DRAFT

TMDL Development Turkey Island Creek and James River Westover to Claremont, VA

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Virginia Department of Environmental Quality

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Background and Applicable Standards

There are six *E. coli* impairments in this study area including segments on the James River, Western Run, Crewes Channel, West Run, Wards Creek, and Upper Chippokes Creek. These segments are listed on Virginia's 303(d) list because 10% or more of the total samples in the assessment period exceeded the Primary Contact Use (recreational/swimming) *E. coli* instantaneous standard of 235 colony forming unit per 100 mL (cfu/100 mL). The area of interest in this project spans over parts of Henrico, Charles City, Prince George, and Surry counties in Virginia.

In Virginia, once a water body violates a given standard, a Total Maximum Daily Load (TMDL) must be developed. The TMDL is a pollution budget that determines the amount of pollutant the water body can receive in a given period of time and still meet the intended standard. **Table ES. 1** shows the details of impairments including stream name, impairment length and description, and percentage violation of the water quality standard.

The Virginia Department of Environmental Quality (VADEQ) has recently moved towards a more cost effective approach to conducting TMDLs. The new approach is called Nested TMDL where the TMDL is developed for a "larger" geographic area that contains smaller sub-areas with impaired segments that formerly were the basis of TMDL projects. These large geographic units are herein called “nested TMDL units” or “NTUs” because they consist of watersheds that formerly were the basis of TMDL projects. Using this approach, NTUs are designed to provide TMDLs that are cost effective, while being scientifically defensible.

Based on this approach, the study area was divided into three NTUs. First, the Turkey Island Creek (NTU 93.1) drainage area which is approximately 12,000 acres and contains the impairments on Crewes Channel and Western Run. The second NTU in the project is NTU 91.1 which includes the drainage area around the James River from Westover to Chippokes Point and is approximately 86,000 acres. NTU 91.1 contains the impairments on West Run and Wards Creek. The third unit is NTU 90.2 and is immediately downstream of NTU 91.1. NTU 90.2 is approximately 30,000 acres and contains the drainage area between Chippokes Point and Claremont. This NTU contains the impairments on the James River and Upper Chippokes Creek.

Table ES. 1 Impairments within the study area.

Stream Name Impairment ID	Impairment(s) Type	Initial Listing Year	2010 River Miles/ Square Miles	2010 Listing Violation %	Impairment Location Description
James River VAP-G04E_JMS03A04	E. coli	2010	3.76[1]	20 EC	From Brandon Point to the transition boundary at approximately river mile 52.08.
Crewes Channel VAP-G02R_CCH01A00	E. coli	2008	3.19	12.5 EC	From its headwaters downstream to the Turkey Island Creek confluence (tidal limit).
Wards Creek VAP-G04R_WRD01A00	E. coli	2006	8.46	18 EC	From its headwaters to the tidal limit.
Upper Chippokes Creek VAP-G04R_UCK01A08	E. coli	2008	5.61	20 EC	From its headwaters downstream its tidal limit.
West Run VAP-G03R_WER03A00	E. coli	2010	1.86	16.7 EC	From its confluence with East Run downstream to backwaters of Harrison Lake.
Western Run VAP-G02R_WSN01A00	E. coli	2006	1.84	37.5 EC	From its headwaters downstream to confluence with Turkey Island Creek.

Bacteria impairments are based on the instantaneous *E. coli* WQS of 235 cfu/100 mL when violations exceed 10% for samples collected during the most recent data period assessment unless otherwise noted.

[1] Estuarine waters

TMDL Endpoint and Water Quality Assessment

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. Whereas the Instantaneous Maximum Standard of 235 cfu/100 mL with no greater than 10% violations is used to assess waters based on monthly or bimonthly samples, for TMDL development, the in-stream *E. coli* target is a geometric mean not exceeding 126 cfu/100 mL.

Source Assessment

Sources of bacteria were identified and quantified in the study area. Sources included point sources as well as non-point sources. The quantification of sources is important to determine the baseline of current conditions that are contributing to the impairment. Sources of bacteria included human, livestock, wildlife, pets, as well as permitted point sources.

Modeling Procedures

Computer modeling is used to relate the sources on the ground to the water quality in the streams and rivers. This is important since not every colony of bacteria in the study area ends up in the streams and rivers. Computer models help quantify the portion of bacteria within the study area that ends up in the stream and the impact of die-off.

The computer modeling process consists of several steps. First, the characteristics of the drainage area including land use, slopes, stream network, and soil properties, are entered into the model. Bacteria loads and parameters influencing bacteria are also entered into the corresponding model. A process known as calibration is then conducted by comparing model simulations with monitored field data. Model parameters are adjusted during calibration to minimize the error between simulated and monitored values. This process is conducted for hydrology (flow) as well as water quality. Once the model is calibrated, it is then used to determine the existing water quality conditions in the study area and may be used to determine the reductions necessary to meet the water quality standard.

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform. For purposes of modeling the study area, the drainage area was divided into forty two (42) subwatersheds. The subdivision of entire area into smaller contributing areas allows for the placement of sources at the proper geographic location and better resemblance of actual connectivity of streams as observed in the real world.

Hourly precipitation data was available within the watershed at the Hopewell NCDC Coop station #444101. Missing values were filled using daily precipitation from the Petersburg NCDC Coop station #446656.

Hydrologic parameters for the study area were obtained using the paired-watershed approach were parameter adjustment from the initial estimates is based on the previously calibrated Chickahominy River watershed.

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock. Contributions from all of these sources were updated to current conditions to establish existing conditions for the watershed.

The *E. coli* calibration was conducted using monitored data collected at multiple VADEQ monitoring stations for the period of October 2003 to September 2006. Water quality validation was conducted using data collected from multiple VADEQ monitoring stations for the period of October 2006 to September 2009.

Load Allocation Scenarios

Once the model was calibrated, the next step was to simulate reducing various source loads to levels that would result in attainment of the water quality standards. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Virginia's water quality standard does not permit any exceedances, therefore, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100 mL geometric mean). The final bacterial TMDLs for the study area NTUs include a 100% reduction in bacteria load from straight pipes. The final TMDL information is shown in **Table ES. 2**.

Allocation scenarios were run for all impaired subwatersheds and outlets of NTUs until all simulated *E. coli* concentrations were allocated to 0% exceedances. The reductions called for in the TMDL apply to the entire drainage area including all 42 subwatersheds. This however does not mean that each subwatershed will experience the same amount of reduction as all other subwatersheds because reduction will be based on actual, on the ground sources. The TMDL calls for eliminating all straight pipes from the entire drainage area. However, if one of the subwatersheds does not have a straight pipe, no reductions will take place in that subwatershed for the straight pipe category.

Table ES. 2 Annual in-stream cumulative pollutant loads modeled after allocation in the study area.

Pollutant	Units	Impairment and Description	WLA[1]	LA	MOS	TMDL
E. coli	cfu/yr	**Turkey Island Creek NTU 93.1**	5.12E+11	1.99E+13	*Implicit*	2.04E+13
E. coli	cfu/yr	**James River from Westover to Chippokes Point NTU 91.1**	4.29E+13	2.10E+15	*Implicit*	2.14E15
E. coli	cfu/yr	**James River from Chippokes Point to Claremont NTU 90.2**	5.10E+13	2.50E+15	*Implicit*	2.55E15

[1] WLA by permit can be found in Chapter 5.

Implementation

The goal of the TMDL program is to establish a path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the first phase of that effort for the impairments in the study area. Second step is the development of TMDL implementation plans (IP). The final step is to implement the TMDL IPs and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia continues the process of restoring impaired waters and enhancing the value of this important resource.

In some streams for which a TMDL has been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed or modified. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. Should a UAA be conducted for use removal or change be recommended in the future for any of the waterbodies within this study, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Public Participation

During development of the TMDLs for the impairments in the study area, public involvement was encouraged through a first public meeting (8/2/2011), and a set of final public meetings (6/26/2013). An introduction of the agencies involved an overview of the TMDL process, details of the pollutant sources, and the specific approach to developing the study area TMDLs were presented at the first public meetings. Public understanding of and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The model simulations and the TMDL load allocations were presented during the final public meetings. There were 30-day public comment periods after both first and final public meetings. Written comments were addressed, and where applicable, reflected in the final document.

1. INTRODUCTION

1.1 Regulations Background

The Clean Water Act (CWA) that became law in 1972 requires that all U.S. streams, rivers, and lakes meet certain water quality standards. The CWA also requires that states conduct monitoring to identify waters that are polluted or do not otherwise meet standards. Through this required program, the state of Virginia has found that many stream segments do not meet state water quality standards for protection of the six beneficial uses: recreation/swimming, aquatic life, wildlife, fish consumption, shellfish consumption, and public water supply (drinking).

When streams fail to meet standards, the stream is “listed” in the current Section 303(d) report as requiring a Total Maximum Daily Load (TMDL). Section 303(d) of the CWA and the U.S. Environmental Protection Agency’s (EPA) Water Quality Management and Planning Regulation (40 CFR Part 130) both require that states develop a Total Maximum Daily Load (TMDL) for each pollutant. A TMDL is a "pollution budget" for a stream; that is, it sets limits on the amount of pollution that a stream can tolerate and still maintain water quality standards. In order to develop a TMDL, background concentrations, point source loadings, and nonpoint source loadings are considered. A TMDL accounts for seasonal variations and must include a margin of safety (MOS).

Once a TMDL is developed and approved by EPA, measures must be taken to reduce pollution levels in the stream. Virginia’s 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states in section 62.1-44.19:7 that the *“Board shall develop and implement a plan to achieve fully supporting status for impaired waters”*. The TMDL Implementation Plan (IP) describes control measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), which should be implemented in a staged process. Through the TMDL process, states establish water-quality based controls to reduce pollution and meet water quality standards.

1.2 *Study area Characteristics*

The Study area (USGS Hydrologic Unit Code 02080206) is located in Henrico, Charles City, Prince George and Surry Counties, Virginia. This watershed is a part of the James River basin, which drains to the Chesapeake Bay. The location of the watershed is shown in **Figure 1.1**. The area is divided into three nested TMDL units (NTUs). The Turkey Island Creek (NTU 93.1) drainage area is approximately 12,000 acres. The second NTU in the project is NTU 91.1 which includes the drainage area around the James River from Westover to Chippokes Point and is approximately 86,000 acres. The most downstream NTU 90.2 is approximately 30,000 acres draining the area between Chippokes Point and Claremont on the James River.

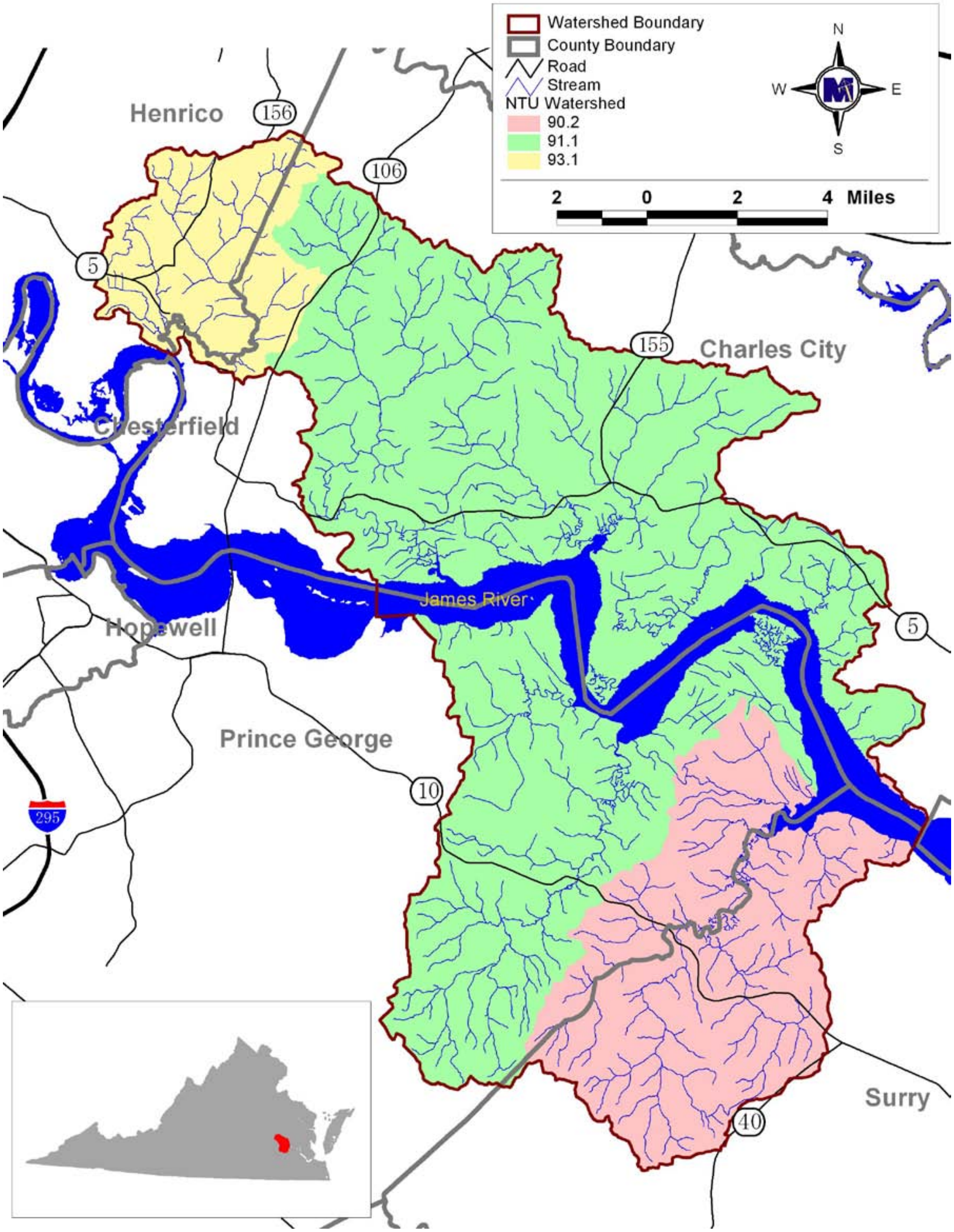

Figure 1.1 Location of the Study area.

The study area is located within the level III Southeastern Plains (65) (Level IV subset – Rolling Coastal Plain (65m). The Southeastern Plains ecoregion (65) has elevations from sea level to 300 feet. The geology is primarily newer sedimentary rock. Stream flow is very sluggish and stream bottoms are sandy. Swampy stained water is common. The Level IV area has a little more gradient and more defined stream flow than streams further east.
(http://www.eoearth.org/article/Ecoregions_of_Delaware%2C_Maryland%2C_Pennsylvania%2C_Virginia%2C_and_West_Virginia_%28EPA%29).

As for the climatic conditions in the study area, during the period from 1916 to 2010 Hopewell, Virginia (NCDC station# 444101) received an average annual precipitation of 44.13 inches, with 56% of the precipitation occurring during the May through October growing season (SERCC, 2011). Average annual snowfall is 7.8 inches, with the highest snowfall occurring during January (SERCC, 2011). The highest average daily temperature of 90.3 ºF occurs in July, while the lowest average daily temperature of 30.3 ºF occurs in January (SERCC, 2011).

Land use in the study area was characterized using the National Land Cover Database 2001 (NLCD). The land cover in all three NTUs is rather similar with forest cover accounting for approximately 55 to 65% of the land while agricultural lands comprise roughly 20 to 25% of the drainage area. Developed land covers account for a very small portion of all watersheds in the study area.

1.3 Turkey Island Creek and James River Westover to Claremont Recreation Use Impairments

There are six different impaired streams in this study area: James River, Crewes Channel, Wards Creek, Upper Chippokes Creek, West Run and Western Run as shown in **Table 1.1**. In the sections below each impaired stream segment is described.

The Virginia Department of Environmental Quality has recently moved towards a more cost effective approach to conducting TMDLs. In the new approach, TMDLs may be developed for large areas containing several impaired stream segments. These large geographic units are herein called "nested TMDL units" or "NTUs" because they consist of watersheds that formerly were the basis of TMDL projects. Using this approach, NTUs are designed to provide TMDLs that are cost effective, while being scientifically defensible.

The building blocks for the NTUs are U. S. Geological Survey (USGS) 12-digit hydrologic units (HUCs). The HUCs were attributed with land cover and use values through GIS-extraction of information from the National Land Classification Dataset (2001), hydrologic connectivity from the USGS National Watershed Boundary dataset, and U. S. Environmental Protection Agency Ecoregion Level III features. HUCs were aggregated in an upstream fashion if their properties indicated the likelihood of similar TMDL conclusions. Aggregation continued until a HUC was encountered that had a substantially different potential TMDL conclusion, was a headwater, or had exceeded the cluster size limit. When a TMDL is to be developed for an impaired segment within a nested area, a decision is made as to whether develop the TMDL only for that segment or expand the TMDL development for the entire NTU.

The current project contains three NTUs. The first NTU is Turkey Island Creek which discharges into the James River approximately 11 stream miles upstream of Westover. This NTU is herein called NTU 93.1 and contains impaired segments on Western Run and Crewes Channel. Second NTU is the James River from Westover to Chippokes Point. This NTU is herein called NTU 91.1 and contains impaired stream segments on Wards Creek and West Run. Immediately downstream is the NTU from Chippokes Point to Claremont and is herein called NTU 90.2. NTU 90.2 contains impaired segments on Upper Chippokes Creek and the James River. The impairments are discussed below in further details. Summary of impairments is given in Table 1.1. Graphical representation of impaired segments is shown in **Figure 1.2**.

1.3.1 James River (VAP-G04E_JMS03A04)

The James River in Charles City, Prince George and Surry Counties, VA flows south-east until reaching the Chesapeake Bay.

The James is listed as impaired from Brandon Point downstream to the Chickahominy River confluence (3.76 square miles). It was initially listed in 2010 as impaired for not supporting the recreation/swimming use. VADEQ monitoring at station 2-JMS052.02 showed a 20% bacteria standard violation rate in the 2010 assessment.

This segment was delisted during the course of the TMDL development. However, a decision was made by DEQ to continue with developing a TMDL for the segment because the violation rate is close to DEQ's impairment threshold of 10%.

1.3.2 Crewes Channel (VAP-G02R_CCH01A00)

Crewes Channel, in Henrico County, flows south until its confluence with Turkey Island Creek.

Crewes Channel from its headwaters downstream to the Turkey Island Creek confluence (tidal limit) (3.19 stream miles) was listed as impaired on the 2008 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-CCH000.54 had a bacteria standard violation rate of 12.5% in the 2010 assessment.

1.3.3 Wards Creek (VAP-G04R_WRD01A00)

Wards Creek, in Prince George County, flows north-east before reaching the tidal limit.

Wards Creek from its headwaters to the tidal limit (8.46 stream miles) was listed as impaired on the 2006 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-WRD005.40 had a bacteria standard violation rate of 18% in the 2010 assessment.

1.3.4 Upper Chippokes Creek (VAP-G04R_WRD01A00)

Upper Chippokes Creek, in Surry County, flows north-east before reaching the tidal limit.

This impaired segment was added to the 2008 impaired waters list for not supporting the recreation/swimming use. This impaired segment extends from its headwaters downstream to its tidal limit (5.61 stream miles). VADEQ monitoring station 2-UCK007.73 had a bacteria standard violation rate of 20% in the 2010 assessment.

1.3.5 West Run (VAP-G03R_WER03A00)

West Run, in Charles City County, flows south before its confluence with the backwaters of Harrison Lake.

West Run from its confluence with East Run downstream to backwaters of Harrison Lake (1.86 stream miles) was listed as impaired on the 2010 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-WER001.93 had a 16.7% violation rate in the 2010 assessment.

1.3.6 Western Run (VAP-G02R_WSN01A00)

Western Run, in Henrico County, flows south south-east before its confluence with Turkey Island Creek.

Western Run from its headwaters downstream to confluence with Turkey Island Creek (1.84 stream miles) was listed as impaired on the 2006 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-WSN000.85 had a 26.7% violation rate in the 2010 assessment.

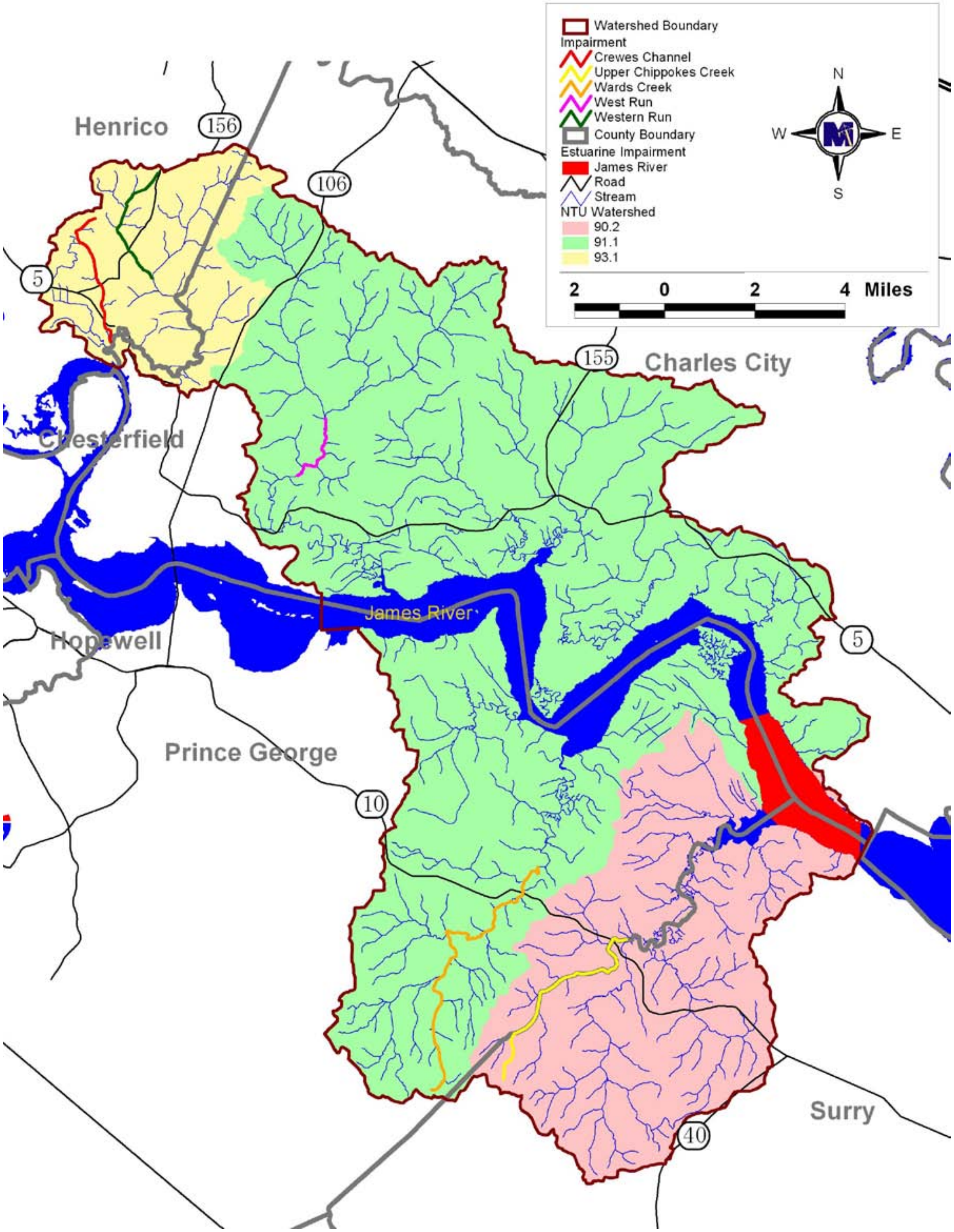

Figure 1.2 The impaired segments in the Study area.

Table 1.1 Impairments within the Turkey Island Creek and James River Westover to Claremont included in this study.

Stream Name Impairment ID	**Impairment(s) Type**	**Initial Listing Year**	**2010 River Miles/ Square Miles[1]**	**2010 Listing Violation%**	**Impairment Location Description**
James River VAP-G04E_JMS03A04	*E. coli*	2010	3.76[1]	20 EC	From Brandon Point to the transition boundary at approximately river mile 52.08
Crewes Channel VAP-G02R_CCH01A00	*E. coli*	2008	3.19	12.5 EC	From its headwaters downstream to the Turkey Island Creek confluence (tidal limit).
Wards Creek VAP-G04R_WRD01A00	*E. coli*	2006	8.46	18 EC	From its headwaters to the tidal limit.
Upper Chippokes Creek VAP-G04R_UCK01A08	*E. coli*	2008	5.61	20 EC	From its headwaters downstream its tidal limit.
West Run VAP-G03R_WER03A00	*E. coli*	2010	1.86	16.7 EC	From its confluence with East Run downstream to backwaters of Harrison Lake.
Western Run VAP-G02R_WSN01A00	*E. coli*	2006	1.84	26.7 EC	From its headwaters downstream to confluence with Turkey Island Creek.

EC - Bacteria impairments are based on the instantaneous *E. coli* WQS of 235 cfu/100 mL when violations exceed 10% for samples collected during the most recent data period assessment unless otherwise noted.
[1] Estuarine waters

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act".

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ⧫
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Virginia adopted its current *E. coli* and *enterococci* standard in January 2003. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals; there is a strong correlation between these and the incidence of gastrointestinal illness. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. Prior to January 2003, Virginia water quality standard in fresh water for swimming/recreational use was based on fecal coliform rather than *E.coli*. The move was based on EPA recommendation that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA pursued the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform.

The criteria which were used in developing the bacteria TMDL in this study are outlined in Section 9 VAC 25-260-170 and read as follows:

A. The following bacteria criteria (colony forming units (CFU)/100 mL) shall apply to protect primary contact recreational uses in surface waters, except waters identified in subsection B of this section:
E. coli bacteria shall not exceed a monthly geometric mean of 126 CFU/100 mL in freshwater.
Enterococci bacteria shall not exceed a monthly geometric mean of 35 CFU/100 mL in transition and saltwater.
1. See 9VAC25-260-140 C for boundary delineations for freshwater, transition and saltwater.
2. Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples.
3. If there are insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E. coli CFU/100 mL .
4. If there are insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 104 CFU/100 mL.
5. For beach advisories or closures, a single sample maximum of 235 E. coli CFU/100 mL in freshwater and a single sample maximum of 104 enterococci CFU/100 mL in saltwater and transition zones shall apply.

2.2 Selection of a TMDL Endpoint

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the bacteria impairments in the study area, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations. In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard.

Since modeling provides simulated output of *E. coli* concentrations at 1-hour intervals, assessment of TMDLs was made using the geometric mean standard. Therefore, the in-stream *E. coli* target for the TMDLs in this study was a monthly geometric mean not exceeding 126 cfu/100 mL.

2.3 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal bacteria monitoring data in the Study area. An examination of data from water quality stations used in the 303(d) 2010 assessment as well as data from other stations was performed.

2.3.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from twenty one (21) VADEQ in-stream monitoring stations.

2.3.1.1 VADEQ Water Quality Monitoring

Data from in-stream water samples, collected at VADEQ monitoring stations from January 2001 to January 2011 (**Figure 2.1**), were analyzed for fecal coliform (Table **2.1** and *E. coli* (**Table 2.2**). Samples were taken for the express purpose of determining compliance with the state instantaneous bacteria standards. Until recent years, and as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a detection limit (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported values of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or 16,000 cfu/100 mL most likely represent concentrations in excess of these values. *E. coli* concentrations can also have varying minimum and maximum laboratory detection concentrations depending on when the sample was analyzed. Information in the tables is arranged in alphabetical order by stream name then from downstream to upstream station location.

Figure 2.1 Location of VADEQ water quality monitoring stations in the Study area.

Table 2.1 Summary of fecal coliform (cfu/100 mL) data collected by VADEQ from January 1990 – August 2011.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Bailey Branch	2-BLB001.19	10/2005 - 11/2005	3	120	340	230	230	110	0.0
Bailey Branch	2-BLB002.04	4/2003	1	50	50	50	NA	NA	0.0
Gunns Run	2-GUN004.00	7/1990 - 3/2001	50	18	2,400	166	100	334	2.0
James River	2-JMS055.94	1/1994 – 8/2011	174	2	790	82	25	123	3.4
James River	2-JMS064.52	7/2005	1	25	25	25	NA	NA	0.0
James River	2-JMS066.88	6/2006	1	25	25	25	NA	NA	0.0
James River	2-JMS069.08	1/1994 – 8/2011	174	2	3,500	181	100	420	8.6
Upper Chippokes Creek	2-UCK005.21	8/2008	1	200	200	200	NA	NA	0.0
Wards Creek	2-WRD005.40	8/1990 - 8/2011	92	18	9,200	451	100	1,304	15.2
West Run	2-WER000.02	5/2003 - 10/2004	6	100	2,200	450	100	857	16.7
West Run	2-WER001.93	6/2001 - 5/2003	13	100	400	154	100	113	0.0
West Run X-Trib	2-XUD000.15	4/2003	1	25	25	25	NA	NA	0.0

NA – Not applicable
[1] Based on an instantaneous fecal coliform standard of 400 cfu/100 mL.

Table 2.2 Summary of *E. coli* (cfu/100 mL) data collected by VADEQ from January 2001 – August 2011.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Bailey Branch	2-BLB001.19	12/2005	1	300	300	300	NA	NA	100.0
Bailey Branch	2-BLB002.04	4/2003	1	20	20	20	NA	NA	0.0
Courthouse Creek	2-CRT001.00	6/2005 – 8/2011	14	25	750	173	98	207	21.4
Crewes Channel	2-CCH000.54	5/2004 - 11/2006	16	25	500	136	88	152	12.5
Gunns Run	2-GUN004.00	7/2003 - 4/2008	12	25	400	83	50	105	8.3
James River	2-JMS052.02[2]	6/2007 - 12/2010	22	25	300	105	100	80	9.1
James River	2JMS055.04	8/2010	1	10	10	10	NA	NA	0.0
James River	2-JMS055.94	7/2004 –8/2011	83	25	480	63	25	68	2.4
James River	2-JMS064.52	7/2005	1	20	20	20	NA	NA	0.0
James River	2-JMS066.88	6/2006	1	10	10	10	NA	NA	0.0
James River	2-JMS069.08	7/2004 – 8/2011	82	25	1,100	103	88	145	7.3
Turkey Island Creek	2-TIC002.69	6/2005 – 7/2011	14	25	220	88	88	59	0.0
Upper Chippokes Creek	2-UCK001.23	8/2003 - 3/2005	10	25	280	61	25	81	10.0
Upper Chippokes Creek	2-UCK005.21	8/08	1	90	90	90	NA	NA	0.0
Upper Chippokes Creek	2-UCK007.73	5/2005 - 11/2006	10	25	1,200	245	63	407	20.0
Wards Creek	2-WRD005.40	8/2003 - 12/2010	49	10	1,800	178	100	338	14.3
West Run	2-WER000.02	4/2003 - 10/2008	8	25	25	25	25	0	0.0
West Run	2-WER001.93	1/2007 - 11/2008	12	3	300	122	100	97	16.7
West Run X-Trib	2-XUD000.15	4/2003	1	10	10	10	NA	NA	0.0
Western Run	2-WSN000.85	5/2004 - 11/2006	16	25	1,000	249	128	293	37.5

NA – Not applicable
[1] Based on the current instantaneous *E. coli* standard of 235 cfu/100 mL.
[2] This station is the listing station for the impaired segment on the James River (VAP-G04E_JMS03A04). This segment was delisted during the course of the TMDL development. However, a decision was made by DEQ to continue with developing a TMDL for the segment because the violation rate is close to DEQ's impairment threshold of 10%.

3. BACTERIA SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal bacteria in the study area. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner and citizen input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Appendix B. To adequately represent the spatial variation in the watershed, the drainage area was divided into forty two (42) subwatersheds (**Figure 3.1**). Source assessment is conducted on subwatershed level where estimates of all potential pollutants are generated for each individual subwatershed.

3.1 Assessment of Permitted Sources

Table 3.1 lists permitted point sources that discharge to surface water bodies in the study area. The permitted facilities within the project watershed in Table 3.1 are regulated through the Virginia Pollutant Discharge Elimination System (VPDES). The use of “UT” in this table refers to unnamed uributaries. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain an E. coli concentration below 126 cfu/100 mL, the current standard. One method for achieving this goal is chlorination, especially with regard to single family home permits. Chlorine is added to the discharge stream at levels intended to kill pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard. There are four individual VPDES permits (Table 3.1) and two single family home permits within the study area permitted by DEQ at this time (Table 3.2).

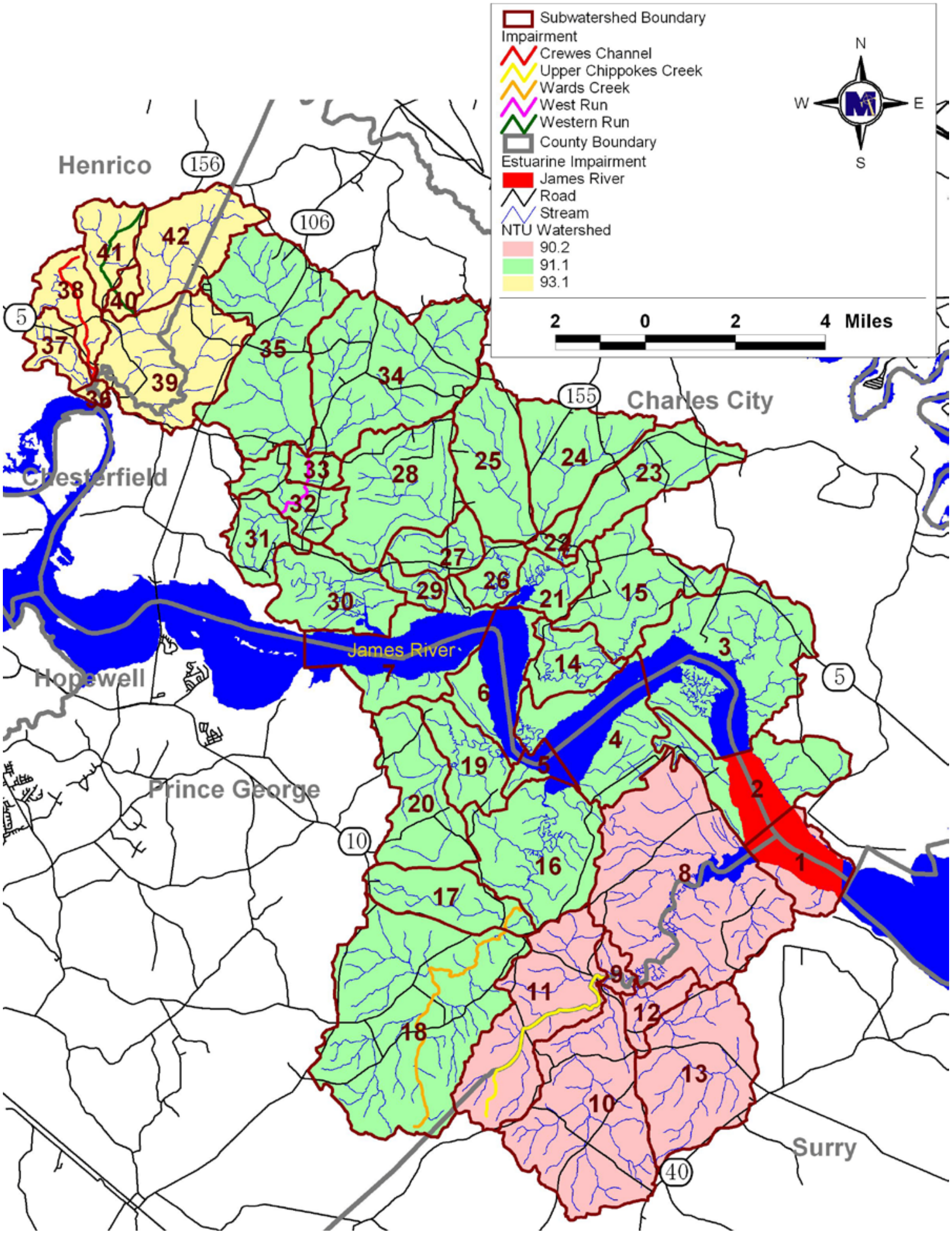

Figure 3.1 All subwatersheds delineated for modeling in the study area.

Table 3.1 Summary of individual VPDES point sources study area.

Permit	Receiving Stream(s)	Facility Name	Permitted for *E. coli* Control
VA0060585	Courthouse Creek	Charles City Administration Building	Yes
VA0021261	Unnamed Trib of Glebe Creek	Ruthville Community Center WWTP	Yes
VA0079057	East Run	Sign Post Estates WWTP	Yes
VA0086673	Courthouse Creek	Charles City County Schools WWTF	Yes

Table 3.2 Single family home permits in the Study area.

Permit	Receiving Stream	Facility Type
VAG404253	UT Wards Creek	Domestic
VAG404206	UT Turkey Island Creek	Domestic

Table 3.3 shows the Municipal Separate Storm Sewer System (MS4) permits. These are areas of land with stormwater runoff collection that discharge to surface waters. The land area within these permit boundaries has bacteria from land-based sources (pet, human, wildlife) which can be present in the runoff.

Table 3.3 Permits for MS4s in the study area.

Permit	Phase	Facility Name	Bacteria Contribution
VA0088617	Phase I	Henrico County	Yes

3.2 Assessment of Nonpoint Sources

Both residential and agricultural nonpoint sources of fecal coliform bacteria were considered in the study area. Sources include residential sewage disposal systems, land application of waste (livestock), livestock, wildlife, and pets. Sources were identified and enumerated. Where appropriate, spatial distribution of sources was also determined.

3.2.1 Septic Systems and Straight Pipes

Population, housing units, and type of sewage treatment from U.S. Census Bureau (USCB, 1990, 2000) were calculated using GIS (**Table 3.4**). In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool or the sewage is disposed of in some other way. The Census category “Other Means” includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category were assumed to be disposing of sewage via a straight pipe (direct stream outfall).

The number of houses with septic systems was estimated by subwatershed. The accuracy of the initial estimates was enhanced by obtaining geographic information from some of the counties detailing the locations of septic systems. The number of houses with failing septic systems was estimated based on the assumption that each septic systems fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with regions Health Departments and feedback was obtained and used in adjusting numbers. Comments from multiple districts were incorporated and the initial estimates were generally reduced. In the case of straight pipes, the estimates were reduced considerably. The estimates shown in **Table 3.4** are given by subwatershed which correspond to geographic illustration shown in Figure 3.1.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal bacteria is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal bacteria to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors, previously performed by MapTech (MapTech, 1999), showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech previously sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 mL (MapTech, 1999). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.4 Human population, housing units, houses on sanitary sewer, septic systems, and straight pipes for areas contributing to impaired segments in the Study area.

Sub-watershed	Human Population	Housing Units	Homes with Sewer	Homes with Septic	Estimated Homes with Straight Pipes	Estimated Homes with Failing Septic Systems
1	151	144	27	117	0	4
2	64	27	0	27	0	1
3	112	53	0	53	0	2
4	12	10	0	10	0	0
5	0	0	0	0	0	0
6	16	8	0	8	0	0
7	27	13	0	13	0	0
8	273	111	19	92	0	3
9	14	5	0	5	0	0
10	145	70	2	67	1	2
11	206	87	3	83	1	3
12	7	6	1	5	0	0
13	258	94	8	85	1	3
14	17	9	0	9	0	0
15	176	94	0	93	1	3
16	90	41	0	41	0	1
17	196	89	0	89	0	3
18	735	334	0	333	1	11
19	0	0	0	0	0	0
20	70	32	0	32	0	1
21	113	57	0	57	0	2
22	0	1	0	1	0	0
23	56	52	0	51	1	2
24	357	155	0	153	2	5
25	154	69	2	66	1	2
26	43	23	0	23	0	1
27	69	29	1	28	0	1
28	255	115	4	109	2	4
29	5	3	0	3	0	0
30	41	24	0	24	0	1
31	125	58	0	57	1	2
32	211	113	0	112	1	4
33	79	29	0	29	0	1
34	1,220	509	12	494	3	16
35	845	376	5	369	2	12
36	2	1	0	1	0	0
37	11	5	0	5	0	0
38	44	20	0	20	0	1
39	210	95	0	94	1	3
40	2	1	0	1	0	0
41	119	54	0	54	1	2
42	621	281	0	279	1	9
Total	*7,151*	*3,297*	*84*	*3,192*	*21*	105

3.2.2 Biosolids

Between 2001 and 2011 biosolids were applied to numerous fields within the study area. The total amount of biosolids applied was 24,712 dry tons (Table 3.5). Records were supplied by VADEQ and a great amount of effort went into collecting and verifying them. The task of regulating biosolids applications is the responsibility of the Virginia Department of Environmental Quality. Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. Class B biosolids may not have a fecal coliform density greater than 1,995,262 cfu/g (total solids). Application rates must be limited to a maximum of 15 dry tons/acre per three-year period.

Table 3.5 Application of biosolids within the study area (2001 – 2011).

Year	Dry Tons	
	Turkey Island Creek (NTU 93.1)	James River and Tributaries (NTU 91.1 + NTU 90.2)
2001	1,206	1,605
2002		2,743
2003	681	3,408
2004	1,228	2,366
2005	2,224	508
2006		929
2007		1,435
2008		2,632
2009	747	1,168
2010		1,090
2011		742
Total	**6,086**	**18,626**

3.2.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the study area and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured by MapTech (MapTech, 1999). Fecal coliform density for dogs and cats was previously measured from samples collected by MapTech (MapTech, 1999). A summary of the data collected is given in **Table 3.6. Table 3.7** lists the domestic animal populations for impairments in the study area by subwatershed.

Table 3.6 Domestic animal population density, waste load, and fecal coliform (FC) density.

	Dog	Cat
Population Density (an/house)*	0.534	0.598
Waste load (g/an-day)**	450	19.4
FC Density (cfu/g)	480,000	9

* animals per house
** grams per animal per day

Table 3.7 Estimated domestic animal populations in areas contributing to impaired segments in the study area.

Sub-watershed	Dogs	Cats
1	77	86
2	14	16
3	28	32
4	5	6
5	0	0
6	4	5
7	7	8
8	59	66
9	3	3
10	37	42
11	46	52
12	3	4
13	50	56
14	5	5
15	50	56
16	13	14
17	36	41
18	97	109
19	4	5
20	20	23
21	30	34
22	1	1
23	28	31
24	83	93
25	37	41
26	12	14
27	15	17
28	61	69
29	2	2
30	13	14
31	31	35
32	60	68
33	15	17
34	272	304
35	201	225
36	1	1
37	3	6
38	11	11
39	50	41
40	1	1
41	29	31
42	148	167
Total	1,662	1,852

3.2.4 Livestock

The predominant type of livestock in the study area is beef cattle and horses, although other types of livestock identified were considered in modeling the watershed. The estimates shown in **Table 3.8** are given by sub-watershed which correspond to geographic illustration shown in Figure 3.1. Animal populations were based on communication with VADEQ, Colonial Soil and Water Conservation District, James River Soil and Water Conservation District, and Peanut Soil and Water Conservation District, watershed visits, and communication with citizens at the first public meeting and afterwards. The livestock populations within the Turkey Island Creek watershed (sub-watersheds 36 to 42) were based mostly on a VADEQ survey that was conducted solely for the purpose of this project.

Table 3.8 Livestock populations in areas contributing to impaired segments in the study area.

Study area	Beef	Beef Calves	Horse	Sheep	Hog
1	0	12	0	1	0
2	16	12	32	0	0
3	3	4	5	0	0
4	18	14	35	0	0
5	0	0	0	0	0
6	8	7	16	0	0
7	3	4	6	0	0
8	27	42	58	3	0
9	0	10	1	0	0
10	0	46	0	6	0
11	0	250	19	2	0
12	0	6	0	1	0
13	0	20	0	5	0
14	2	3	0	0	0
15	3	7	0	0	0
16	12	9	25	0	0
17	6	4	13	0	0
18	37	27	78	0	0
19	5	3	10	0	0
20	6	5	13	0	0
21	1	2	0	0	0
22	1	2	0	0	0
23	3	7	0	0	0
24	3	6	0	0	0
25	4	8	0	0	100
26	1	1	0	0	0
27	3	6	0	0	0
28	4	9	0	0	0
29	2	3	0	0	0
30	6	12	0	0	0
31	1	2	0	0	0
32	1	3	0	0	0
33	0	1	0	0	0
34	4	9	0	0	0
35	4	7	0	0	0
36	0	0	0	0	0
37	25	15	7	6	0
38	0	0	0	4	0
39	0	0	20	1	0
40	0	0	0	2	0
41	0	0	2	1	0
42	0	0	8	2	0
Total	209	578	348	34	100

Values of fecal coliform density and waste storage die-off of livestock sources were based on sampling previously performed by MapTech (MapTech, 1999). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in **Table 3.9.**

Table 3.9 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Hog (135 lb)	11.3	400,000	0.8
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA

Fecal bacteria produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. **Table 3.10** shows the average percentage of collected livestock waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities may have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.10 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total Beef	Land use
January	4.00	Cropland
February	4.00	Cropland
March	12.00	Cropland
April	12.00	Cropland
May	12.00	Cropland
June	8.00	Pasture
July	8.00	Pasture
August	8.00	Pasture
September	12.00	Cropland
October	12.00	Cropland
November	4.00	Cropland
December	4.00	Cropland

Some livestock were expected to deposit a portion of waste on land areas. The percentage of time spent on pasture for beef cattle was estimated based on projects in other areas of Virginia. Horses and sheep were assumed to be in pasture 100% of the time.

It was assumed that beef cattle were expected to make a contribution through direct deposition with access to flowing water. For areas where direct deposition by cattle is assumed, the average amount of time spent by beef cattle in stream access areas for each month is given in **Table 3.11**.

Table 3.11 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.2.5 Wildlife

The predominant wildlife species in the study area were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, and other state and local officials. Population densities were calculated from data provided by VDGIF and FWS, and are listed in **Table 3.12** (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987; Mayhorn, 2005).

Table 3.12 Wildlife population densities for the Study area.

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0344	0.00907	0.003197	0.006515	0.3125	0.0703	0.25

The numbers of animals estimated to be in the study area are reported in Table 3.13**.** Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999).

Table 3.13 Estimated wildlife populations in the study area.

Study area	Deer	Turkey	Beaver	Raccoon	Muskrat	Duck	Goose
Turkey Island Creek (NTU 93.1)	405	105	212	1,179	379	39	39
Westover to Chippokes Point (NTU 91.1)	2,596	681	811	5,182	7,182	748	734
Chippokes Point to Claremont (NTU 90.2)	938	246	287	1,873	2,122	222	217

Fecal coliform densities and fecal production information are reported in **Table 3.14**. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech (MapTech, 1999). The only value that was not obtained from MapTech sampling in the watershed was for beaver.

Table 3.14 Wildlife daily waste production and average fecal coliform densities.

Animal Type	Waste Load (g/an-day)	Fecal Coliform Density (cfu/g)
Raccoon	450	2,100,000
Muskrat	100	1,900,000
Beaver[1]	200	1,000
Deer	772	380,000
Turkey[2]	320	1,332
Goose[3]	225	250,000
Duck	150	3,500

[1] Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2] Waste load for domestic turkey (ASAE, 1998).
[3] Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003)

Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. **Table 3.15** summarizes the wildlife habitat and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream).

Table 3.15 Wildlife percentage of time spent in stream access areas and habitat.

Animal	Portion of Day in Stream Access Areas (%)	Habitat
Raccoon	5	**Primary** = region within 600 ft of perennial streams **Secondary** = region between 601 and 7,920 ft from perennial streams **Infrequent/Seldom** = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	90	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Beaver	100	**Primary** = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) **Infrequent/Seldom** = rest of the watershed area
Deer	5	**Primary** = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land **Secondary** = low density residential, medium density residential **Infrequent/Seldom** = remaining land use areas
Turkey	5	**Primary** = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land **Secondary** = cropland, pasture **Infrequent/Seldom** = remaining land use areas
Goose	50	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Mallard (Duck)	75	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area

4. BACTERIA MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

This chapter represents a brief description of the modeling procedures. Complete description is presented in Appendix B. Computer modeling is used in this study as a tool that allows simulating the interaction between the land surface and subsurface and the quantities of various bacteria sources by location. The model allows the climatological factors and in particular, precipitation, to drive this interaction. By modeling the watershed conditions and bacteria sources, the model allows quantifying the relationship between sources as they exist throughout the watershed to bacteria concentrations within the watershed. Two modeling approaches were used in the analysis. For the free flowing tributaries, the model used was the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources.

For the tidal James River segments, the Steady State Tidal Prism Model, which is used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model the tidally influenced segments in conjunction with lateral free-flowing impairment creeks and input from upstream James River. The entire length of the James River within the study area is tidally influenced and so are multiple creeks flowing laterally into the James River between Herring Creek upstream, to Upper Chippokes Creek downstream.

To adequately represent the spatial variation in the watershed parameters and pollutant quantification, the drainage area was divided into forty two (42) subwatersheds (Figure 3.1). Hydrologic parameters collected for the watershed were adjusted based on previously conducted hydrologic calibration in nearby projects where flow was calibrated by comparing model output to observed flow.

Once the flow component was built, quantified bacteria sources were entered into the model and a simulated bacteria concentration was generated. The simulated bacteria concentration was calibrated by comparing model simulations of bacteria to observed bacteria values collected by VADEQ at multiple locations. Finally the bacteria concentration was validated using a different time period from the calibration period.

Existing conditions of bacteria were then entered into the model to simulate the baseline conditions. This stage gives an indication of the current, predicted, violation rates of the geometric mean standard. The model was then used in the allocations process where reductions are simulated for various sources until the bacteria geometric mean standard was met. A complete description of the modeling approach is presented in Appendix B.

5. BACTERIAL ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For these impairments, the TMDLs are expressed in terms of colony forming units (or resulting concentration).

Allocation scenarios were modeled using the HSPF model. Scenarios were created by reducing direct and land-based bacteria until the water quality standards were attained. The TMDLs developed for the impairments in the study area were based on the *E. coli* riverine Virginia State standards. As detailed in Section 2.1, the VADEQ riverine primary contact recreational use *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 mL.

According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling bacteria with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a data set containing 493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

where C_{ec} is the concentration of *E. coli* in cfu/100 mL and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period and pollutant loads were adjusted until the standards were met. Load reduction scenarios were run until water quality standard was met at each NTU outlet and at each individual impairment.

5.1 Margin of Safety (MOS)

In order to account for uncertainty in modeled output, a Margin of Safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of bacteria TMDLs is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of these TMDLs. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of these TMDLs are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration, and
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed.
- Modeling all outflow from straight pipes and failing septic systems at the human waste concentration including the gray-water portion.

5.2 Waste Load Allocations (WLAs)

There are six VPDES point source currently permitted to discharge into the study area. The allocation for the discharges is equivalent to their current permit levels (design discharge and 126 cfu/100 mL). Future growth was accounted for by setting aside 2% of the TMDL for growth in the permitted discharge or creation of new ones.

5.3 Load Allocations (LAs)

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (livestock, wildlife, and straight pipes). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads most significantly impact bacteria concentrations during high-flow conditions, while direct deposition NPS most significantly impact low flow bacteria concentrations. When necessary, nonpoint source load reductions are performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs are implemented by land use. Reductions to direct non-point sources were performed by source. Appendix C shows tables of the breakdown of the annual fecal coliform per animal per land use for contributing subwatersheds to each impairment.

5.4 Final Total Maximum Daily Loads (TMDLs)

Allocation scenarios were run until all impairments were allocated to 0% exceedances of all applicable standard. The first table in each of the following three sections represents the scenarios developed to determine the TMDLs. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, a scenario reflects the impact of eliminating direct human sources from straight pipes leading to the final allocation scenario that contains the predicted reductions needed to meet 0% exceedance of all applicable water quality standards. The graphs in the following sections depict the existing and allocated 30-day geometric mean in-stream bacteria concentrations.

The second table in each of the following sections shows the existing and allocated *E. coli* loads that are output from the HSPF model. The third table shows the final annual in-stream allocated loads for the appropriate bacteria species. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The final table is an estimation of the in-stream daily load of bacteria.

5.4.1 Turkey Island Creek (NTU 93.1) - (Crewes Channel and Western Run)

Table 5.1 shows allocation scenarios used to determine the final TMDL for the Turkey Island Creek study area impairments (Crewes Channel (VAP-G02R_CCH01A00) and Western Run (VAP-G02R_WSN01A00)). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100 mL geometric mean). The existing condition, Scenario 1, shows various degrees of violations of the geometric mean standard by location. Scenario 2 (eliminating straight pipe inputs) shows enough improvement and meets the geometric mean standard of 126 cfu/100 mL. Scenario 2 will be the target goal during the implementation of best management practices (BMPs).

Table 5.1 Allocation scenarios for reducing current bacteria loads in the Turkey Island Creek study area (NTU 93.1).

	Percent Reductions to Existing Bacteria Loads									
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *E. coli* Standard percent violations**			
Scenario	**Wildlife Direct**	**Barren[1], Open Space, Forest, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX[2]**	**Straight Pipes**	**LMIR[3]**	**% >126 GM**			
							Sub36	**Sub38**	**Sub40**	**Sub41**
1	0	0	0	0	0	0	13.70	0.00	2.91	52.06
2[4]	0	0	0	0	100	0	0.00	0.00	0.00	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] LMIR – Low-Medium Intensity Residential
[4] Final TMDL Scenario

Figure 5.1 shows the existing and allocated monthly geometric mean *E. coli* concentrations, from the Turkey Island Creek study area at the main watershed outlet (subwatershed 36). The graph shows existing conditions in black, with allocated conditions overlaid in blue.

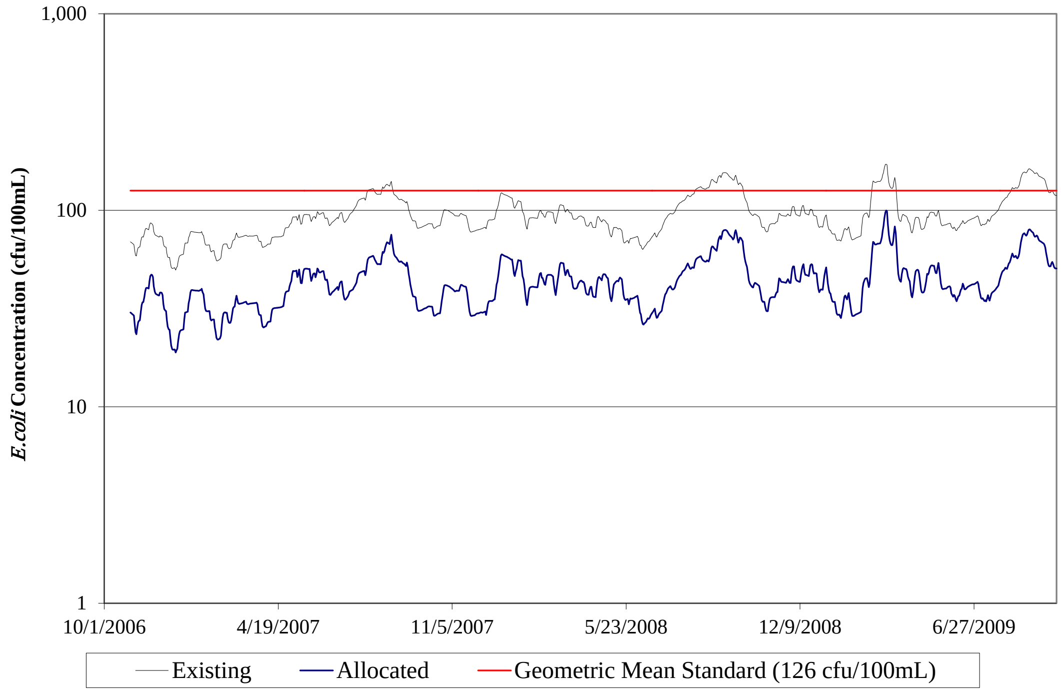

Figure 5.1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 36, Turkey Island Creek NTU 93.1.

Table 5.2 contains estimates of existing and allocated in-stream *E. coli* loads for the Turkey Island Creek area reported as annual cfu per year. The estimates in Table 5.2 are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126 cfu/100 mL geometric mean standard are given in the final column.

Tables C.1 through C.4 in Appendix C include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.2 Estimated existing and allocated *E. coli* in-stream loads in the Turkey Island Creek (NTU 93.1) study area impairments.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Open Space	2.76E+10	2.76E+10	0.0%
	LMIR*	1.10E+12	1.10E+12	0.0%
	Barren**	1.27E+11	1.27E+11	0.0%
	Commercial	1.68E+09	1.68E+09	0.0%
	Forest	4.26E+12	4.26E+12	0.0%
	Pasture	6.99E+12	6.99E+12	0.0%
	Crop	5.33E+12	5.33E+12	0.0%
	Wetland	2.93E+11	2.93E+11	0.0%
	LAX***	1.96E+11	1.96E+11	0.0%
Direct				
	Human	3.03E+12	0.00E+00	100.0%
	Livestock	6.86E+10	6.86E+10	0.0%
	Wildlife	1.46E+12	1.46E+12	0.0%
	Permitted Sources	1.05E+11	1.05E+11	0%
Future Growth	Future Growth	0.00E+00	4.07E+11	NA
Total Loads		**2.30E+13**	**2.04E+13**	**13.2%********

* LMIR – Low-Medium Intensity Residential
** Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX - livestock pasture access near flowing streams.
**** Calculations for total percent reductions are conducted excluding future growth.

Table 5.3 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.3 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Turkey Island Creek (NTU 93.1) study area.

Impairment	WLA[1]	LA	MOS	TMDL
Turkey Island Creek	**5.12E+11**	**1.99E+13**	*Implicit*	**2.04E+13**
VAG404206	*1.74E+09*			
Henrico Co. and VDOT MS4[2]	*1.03E+11*			
Future Load	*4.07E+11*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily in-stream loads for the Turkey Island Creek study area are shown in **Table 5.4.** The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.4 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Turkey Island Creek (NTU 93.1) study area.

Impairment	WLA	LA	MOS	TMDL
Turkey Island Creek	**1.40E+09**	**6.94E+11**	*Implicit*	**6.95E+11**
VAG404206	4.77E+06			
Henrico Co and VDOT MS4	2.83E+08			
Future Load	1.12E+09			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In Tables 5.2 through 5.4, the contribution from land-based sources (LA), as shown in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.2 James River and Tributaries, Westover to Chippokes Point (NTU 91.1) - (West Run and Wards Creek)

Table 5.5 shows allocation scenarios used to determine the final TMDL for the James River and Tributaries, Westover to Chippokes Point (NTU 91.1) which contains the impairments on Wards Creek (VAP-G04R_WRD01A00) and West Run (VAP-G03R_WER03A00). Because Virginia’s water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100 mL geometric mean). The existing condition, Scenario 1, shows various degrees of violations of the geometric mean standard by location. Scenario 2 (eliminating straight pipe inputs) shows enough improvement and meets the geometric mean standard of 126 cfu/100 mL. Scenario 2 will be the target goal during the implementation of best management practices (BMPs).

Table 5.5 Allocation scenarios for reducing current bacteria loads in the James River and Tributaries, Westover to Chippokes Point (NTU 91.1).

	Percent Reductions to Existing Bacteria Loads										
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	VADEQ *E. coli* Standard percent violations				
							% >126 GM				
Scenario	Wildlife Direct	Barren[1], Open Space, Forest, Wetlands	Livestock Direct	Cropland, Pasture, LAX[2]	Straight Pipes	LMIR[3]	Sub2	Sub17	Sub18	Sub32	Sub33
1	0	0	0	0	0	0	0.00	0.00	25.05	32.46	39.12
Upstream James Contribution Inflow Concentration is at Geometric Mean Standard											
2[4]	0	0	0	0	100	0	0.00	0.00	0.00	0.00	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] LMIR – Low-Medium Intensity Residential
[4] Final TMDL Scenario

Figure 5.2 shows the existing and allocated monthly geometric mean *E. coli* concentrations, at the NTU outlet (subwatershed 2). The graph shows existing conditions in black, with allocated conditions overlaid in blue.

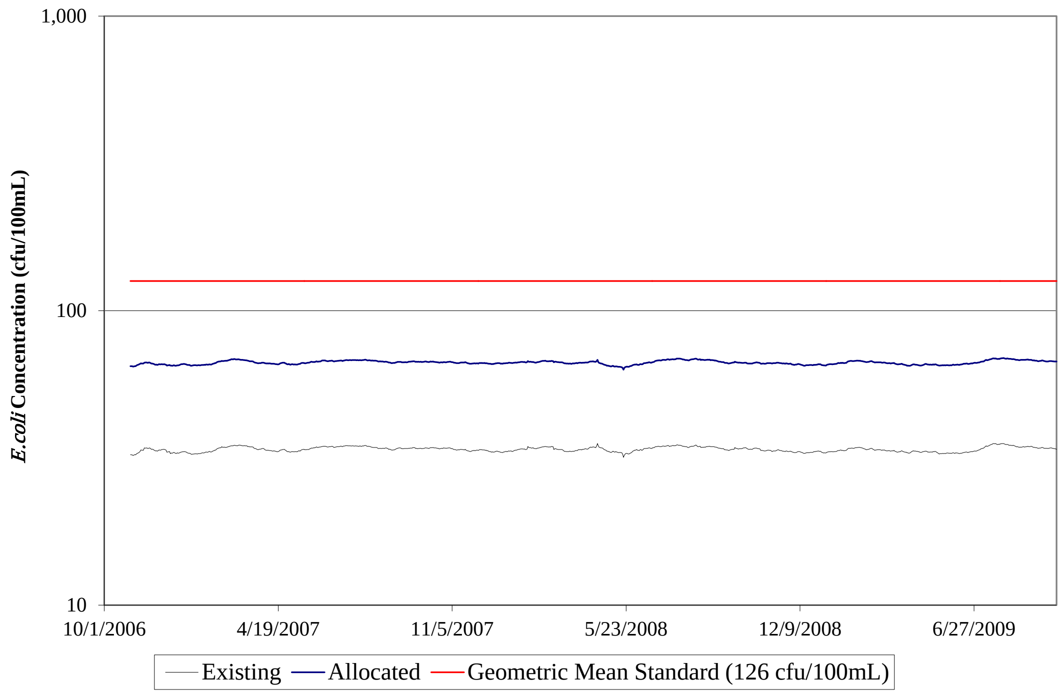

Figure 5.2 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 2, outlet of NTU 91.1.

Table 5.6 contains estimates of existing and allocated in-stream *E. coli* loads for the James River and Tributaries – Westover to Chippokes Point area (NTU 91.1) reported as annual cfu per year. The estimates in Table 5.6 are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126 cfu/100 mL geometric mean standard are given in the final column.

Tables C.5 through C.11 in Appendix C include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.6 Estimated existing and allocated *E. coli* in-stream loads in the James River and Tributaries – Westover to Chippokes Point (NTU 91.1) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Open Space	6.66E+10	6.66E+10	0.0%
	LMIR*	3.93E+11	3.93E+11	0.0%
	Barren**	3.30E+11	3.30E+11	0.0%
	Commercial	1.69E+09	1.69E+09	0.0%
	Forest	4.33E+12	4.33E+12	0.0%
	Pasture	3.30E+12	3.30E+12	0.0%
	Crop	3.99E+12	3.99E+12	0.0%
	Wetland	1.19E+12	1.19E+12	0.0%
	LAX***	1.09E+11	1.09E+11	0.0%
Direct				
	Human	1.40E+12	0.00E+00	100.0%
	Livestock	8.28E+12	8.28E+12	0.0%
	Wildlife	2.12E+14	2.12E+14	0.0%
	Permitted Sources	1.96E+11	1.96E+11	0%
	Upstream James	1.86E+15	1.86E+15	0%
Future Growth	Future Growth	0.00E+00	4.27E+13	NA
Total Loads		**2.10E+15**	**2.14E+15**	**0.1%********

* LMIR – Low-Medium Intensity Residential
** Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX - livestock pasture access near flowing streams.
**** Calculations for total percent reductions are conducted excluding future growth.

Table 5.7 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.7 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the James River and Tributaries-Westover to Chippokes Point (NTU 91.1) study area.

Impairment	WLA	LA	MOS	TMDL
James River (NTU 91.1)	**4.29E+13**	**2.10E+15**		**2.14E+15**
VAG404253	*1.74E+09*			
VA0021261	*1.74E+10*			
			Implicit	
VA0060585	*7.84E+09*			
VA0079057	*1.25E+11*			
VA0086673	*4.36E+10*			
Future Load	*4.27E+13*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily in-stream loads for the James River and Tributaries-Westover to Chippokes Point (NTU 91.1) study area are shown in **Table 5.8**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.8 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the study area impairments.

Impairment	WLA	LA	MOS	TMDL
James River (NTU 91.1)	**1.18E+11**	**2.86E+13**	*Implicit*	**2.87E+13**
VAG404253	4.77E+06			
VA0021261	4.77E+07			
VA0060585	2.15E+07			
VA0079057	3.43E+08			
VA0086673	1.19E+08			
Future Load	1.17E+11			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In Tables 5.6 through 5.8, the contribution from land-based sources (LA), as shown in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.3 James River and Tributaries, Chippokes Point to Claremont (NTU 90.2) - (Upper Chippokes Creek and James River)

Table 5.9 shows allocation scenarios used to determine the final TMDL for the James River and Tributaries, Chippokes Point to Claremont (NTU 90.2) which contains the impairments on Upper Chippokes Creek (VAP-G04R_UCH03A04) and the James River (VAP-G04E_JMS03A04). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100 mL geometric mean). The existing condition, Scenario 1, shows various degrees of violations of the geometric mean standard by location. Scenario 2 (eliminating straight pipe inputs) shows enough improvement and meets the geometric mean standard of 126 cfu/100 mL. Scenario 2 will be the target goal during the implementation of best management practices (BMPs).

Table 5.9 Allocation scenarios for reducing current bacteria loads in the James River and Tributaries, Chippokes Point to Claremont (NTU 90.2).

	Percent Reductions to Existing Bacteria Loads							
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	VADEQ *E. coli* Standard percent violations	
							% >126 GM	
Scenario	Wildlife Direct	Barren[1], Open Space, Forest, Wetlands	Livestock Direct	Cropland, Pasture, LAX[2]	Straight Pipes	LMIR[3]	Sub1	Sub11
1	0	0	0	0	0	0	0.00	33.30
Upstream James Contribution Inflow Concentration is at Geometric Mean Standard								
2[4]	0	0	0	0	100	0	0.00	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] LMIR – Low-Medium Intensity Residential
[4] Final TMDL Scenario

Figure 5.3 shows the existing and allocated monthly geometric mean *E. coli* concentrations, at the main watershed outlet (subwatershed 1). The graph shows existing conditions in black, with allocated conditions overlaid in blue.

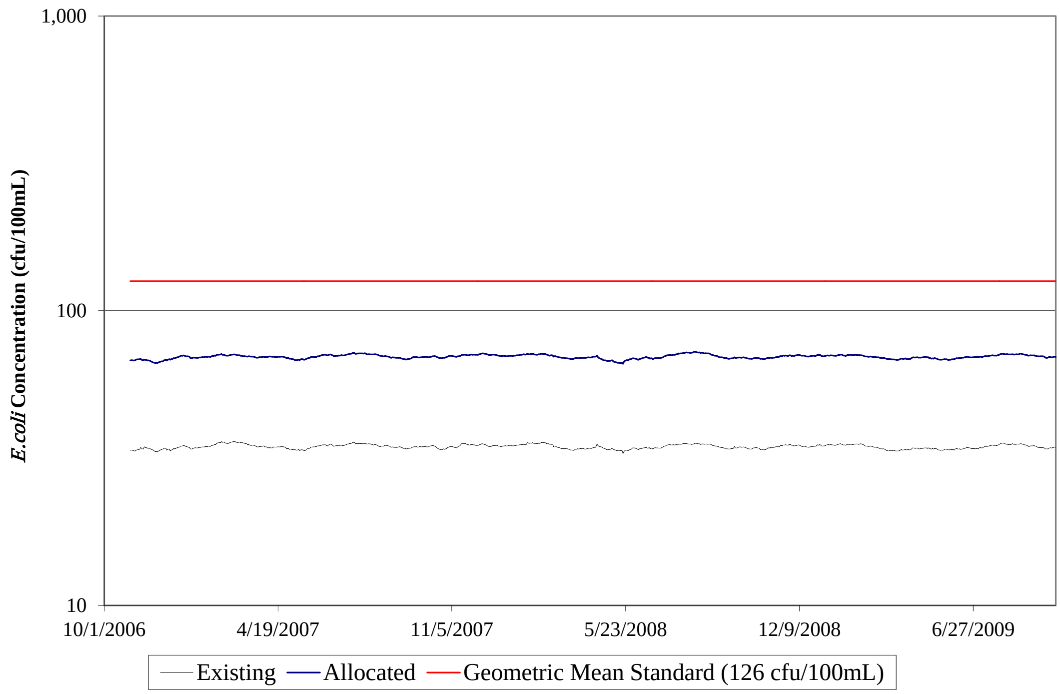

Figure 5.3 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 1, outlet of NTU 90.2.

Table 5.10 contains estimates of existing and allocated in-stream *E. coli* loads for the James River and Tributaries – Chippokes Point to Claremont area reported as annual cfu per year. The estimates in Table 5.10 are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126 cfu/100 mL geometric mean standard are given in the final column.

Tables C.12 through C.15 in Appendix C include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.10 Estimated existing and allocated *E. coli* in-stream loads in the James River and Tributaries – Chippokes Point to Claremont (NTU 90.2) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Open Space	5.19E+10	5.19E+10	0.0%
	LMIR*	7.73E+11	7.73E+11	0.0%
	Barren**	1.16E+11	1.16E+11	0.0%
	Commercial	0.00E+00	0.00E+00	0.0%
	Forest	9.34E+11	9.34E+11	0.0%
	Pasture	1.98E+11	1.98E+11	0.0%
	Crop	2.93E+10	2.93E+10	0.0%
	Wetland	3.21E+11	3.21E+11	0.0%
	LAX***	6.42E+10	6.42E+10	0.0%
Direct				
	Human	1.23E+04	0.00E+00	100.0%
	Livestock	2.91E+12	2.91E+12	0.0%
	Wildlife	1.10E+14	1.10E+14	0.0%
	Permitted Sources	0.00E+00	0.00E+00	0%
	Upstream James	2.41E+15	2.41E+15	0%
Future Growth	Future Growth	0.00E+00	2.53E+13	NA
Total Loads		**2.52E+15**	**2.55E+15**	**<0.0%********

* LMIR – Low-Medium Intensity Residential
** Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX - livestock pasture access near flowing streams.
**** Calculations for total percent reductions are conducted excluding future growth.

Table 5.11 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.11 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the James River and Tributaries- Chippokes Point to Claremont (NTU 90.2) study area.

Impairment	WLA	LA	MOS	TMDL
James River (NTU 90.2)	**5.10E+13**	**2.50E+15**	*Implicit*	**2.55E+15**
Future Load	*5.10E+13*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the James River and Tributaries- Westover to Chippokes Point (NTU 90.2) study area are shown in **Table 5.12**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.12 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the James River and Tributaries- Chippokes Point to Claremont study area impairments.

Impairment	WLA	LA	MOS	TMDL
James River (NTU 90.2)	1.40E+11	3.29E+13	*Implicit*	3.30E+13
Future Load	1.40E+11			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In Tables 5.10 through 5.12, the contribution from land-based sources (LA), as shown in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the two tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

6. IMPLEMENTATION

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. EPA requires that there is reasonable assurance that TMDLs can be implemented. TMDLs represent an attempt to quantify the pollutant load that might be present in a waterbody and still ensure attainment and maintenance of water quality standards. The Commonwealth intends to use existing programs in order to attain water quality goals.

The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1 Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on the VADEQ web site under http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ppp.pdf.

6.2 Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. It enables tracking of water quality improvements following implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

6.3 Implementation of Waste Load Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

6.3.1 Stormwater

VADEQ and VADCR coordinate separate state permitting programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with industrial activities through its VPDES program, while VADCR regulates stormwater discharges from construction sites, and from municipal separate storm sewer systems (MS4s) through the VSMP program. As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented. More information regarding these programs can be found at

http://www.dcr.virginia.gov/soil_&_water/e&s.shtml.

6.3.2 TMDL Modifications for New or Expanding Discharges

Permits issued for facilities with waste load allocations developed as part of a Total Maximum Daily Load (TMDL) must be consistent with the assumptions and requirements of these waste load allocations (WLA), as per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/052011.pdf.

6.4 Implementation of Load Allocations

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

6.4.1 Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003. It is available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.4.2 Staged Implementation Scenarios

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Among the most efficient bacterial BMPs are stream side fencing for cattle farms, pet waste clean-up programs, and government or grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes.

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

If water quality standards are not met upon implementation of all cost-effective and reasonable BMPs, a Use Attainability Analysis (UAA) may need to be initiated since Virginia's water quality standards allow for changes to use designations if existing water quality standards cannot be attained by implementing effluent limits required under §301b and §306 of Clean Water Act, and by implementing cost effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in Section 6.6.

6.4.3 Link to Ongoing Restoration Efforts

Implementation of these TMDLs will contribute to on-going water quality improvement efforts aimed at restoring water quality in the study area watershed. Implementation plan will include measures for the two previously developed bacteria TMDLs in James River for the Turkey Island Creek drainage area. Implementation of these TMDLs will also contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay.

6.4.4 Implementation Funding Sources

The implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund, the Fund has become a significant funding source for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/Programs/Water/CleanWaterFinancingAssistance/WaterQualityImprovementFund.aspx.

6.5 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with *DEQ Guidance Memo No. 04-2005* (http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/042005b.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The details of the follow-up ambient monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office.

VADEQ staff, in cooperation with the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plans. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or to monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on VADEQ's citizen monitoring and QA/QC guidelines is available at http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years.

6.6 Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use.

In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses are expected to be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;

2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;

3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;

4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;

5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or

6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. A UAA may be developed by any stakeholder at any time before, during, or after the TMDL process. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the EPA, will be able to provide comment. Additional information can be obtained at http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityStandards/DesignatedUses.aspx.

The process to address potentially unattainable reductions based on the above is as follows:

As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation is that all controllable sources would be reduced to the maximum extent possible using the implementation approaches described above. VADEQ will continue to monitor water quality in the stream during and subsequent to the implementation of these measures to determine if the water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA may then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E. provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed".

7. PUBLIC PARTICIPATION

Public participation during TMDL development for the Study area was encouraged; a summary of the meetings is presented in **Table 7.1**. The first public meeting took place on August 2, 2011 at the Charles City County Government and School Board Administration Building Charles City, Virginia. ? people attended the meeting. The second public meeting was held on ? ?, 2013 and three ? attended. The meetings were publicized by placing notices in the Virginia Register, signs in the watershed, and emailing notices to local stakeholders and representatives.

Table 7.1 Public participation during TMDL development for the Turkey Island Creek and James River Westover to Claremont, VA study area.

Date	Location	Attendance[1]	Type
8/02/2011	Charles City County Government and School Board Administration Building Charles City, VA	?	1st public
?/?/2013	?	?	2nd public

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of stakeholders' committees, with committee and public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. Stakeholder committees will have the express purpose of formulating the TMDL Implementation Plan. The committees will consist of, but not be limited to, representatives from VADEQ, VADCR and local governments. These committees will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity*. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota.

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition).[2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition*. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* ***Respiration.***

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle*. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology*. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the* *conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metric ton (Mg or t). A unit of mass equivalent to 1,000 kilograms. An annual load of a pollutant is typically reported in metric tons per year (t/yr).

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Most Probable Stressor(s): The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

Narrative criteria*. Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Non-Stressor(s): Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

Numeric targets*. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff*. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more* *than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Polycyclic aromatic hydrocarbons (**PAH**s) are chemical compounds that consist of fused aromatic rings and do not contain heteroatoms or carry substituents. PAHs occur in oil, coal, and tar deposits, and are produced as byproducts of fuel burning (whether fossil fuel or biomass). As a pollutant, they are of concern because some compounds have been identified as carcinogenic, mutagenic, and teratogenic.

Possible Stressor(s): Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works*. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period*. The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity*. Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration*. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone*. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient*. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquatic systems as a result of erosion.

Septic system*. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation*. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Spatial segmentation*. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards*. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Ton (T). A unit of measure of mass equivalent to 2,200 English lbs.

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality*. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

Frequency Analysis of Bacteria Data

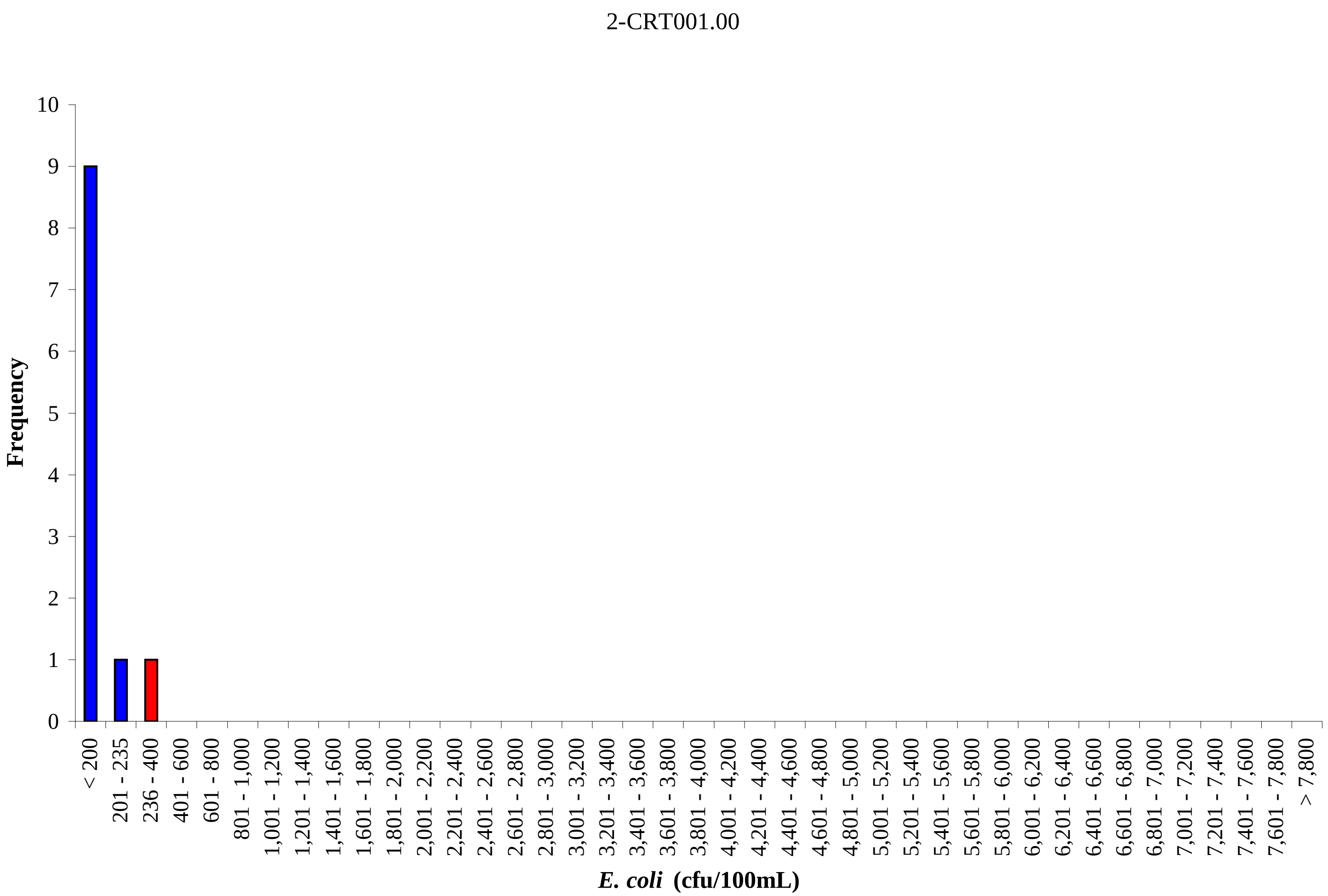

Figure A. 1 Frequency analysis of *E. coli* concentrations at station 2-CRT001.00 in Courthouse Creek for the period from January 2006 to December 2006.

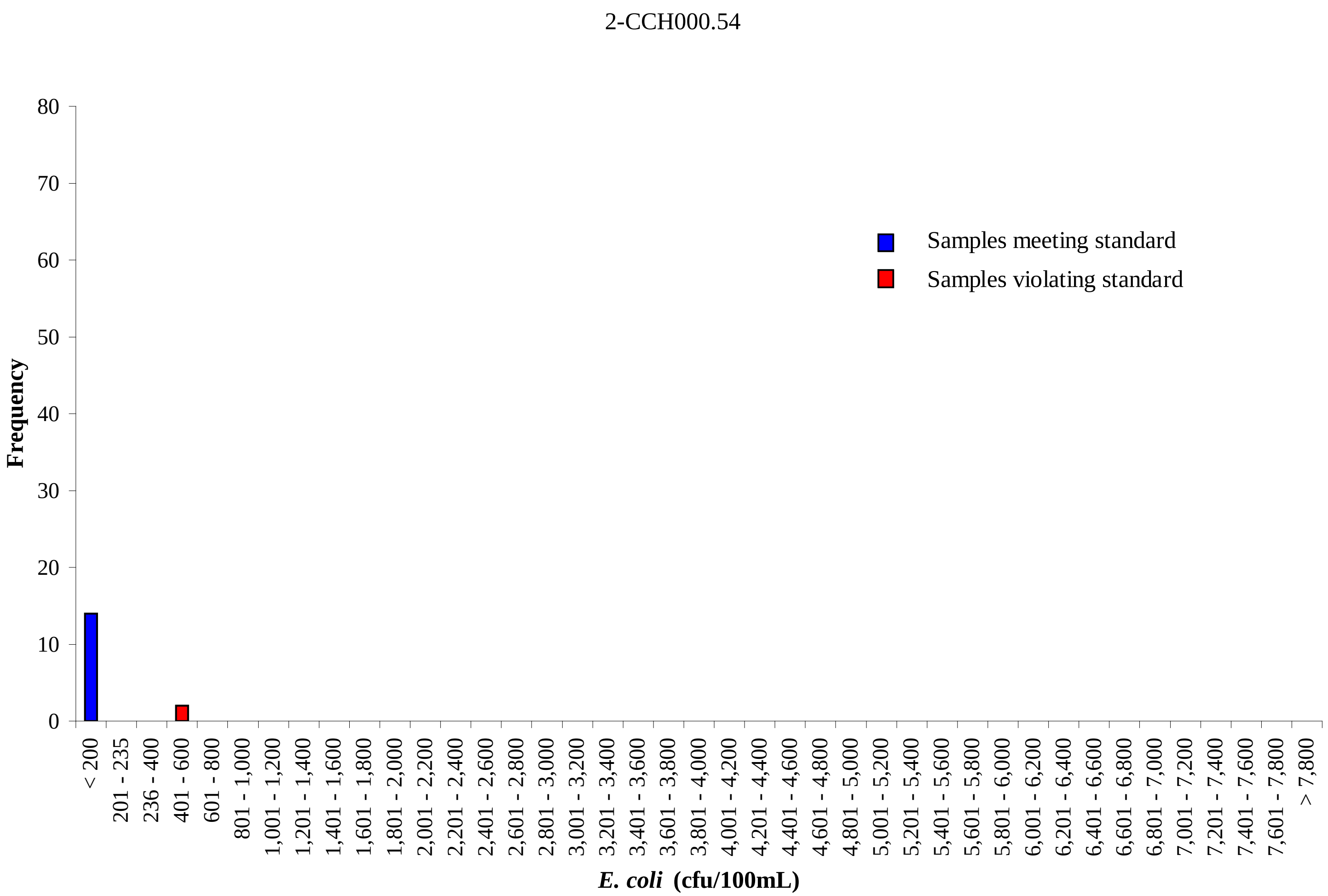

Figure A. 2 **Frequency analysis of *E. coli* concentrations at station 2-CCH000.54 in Crewes Channel for the period from May 2004 to November 2006.**

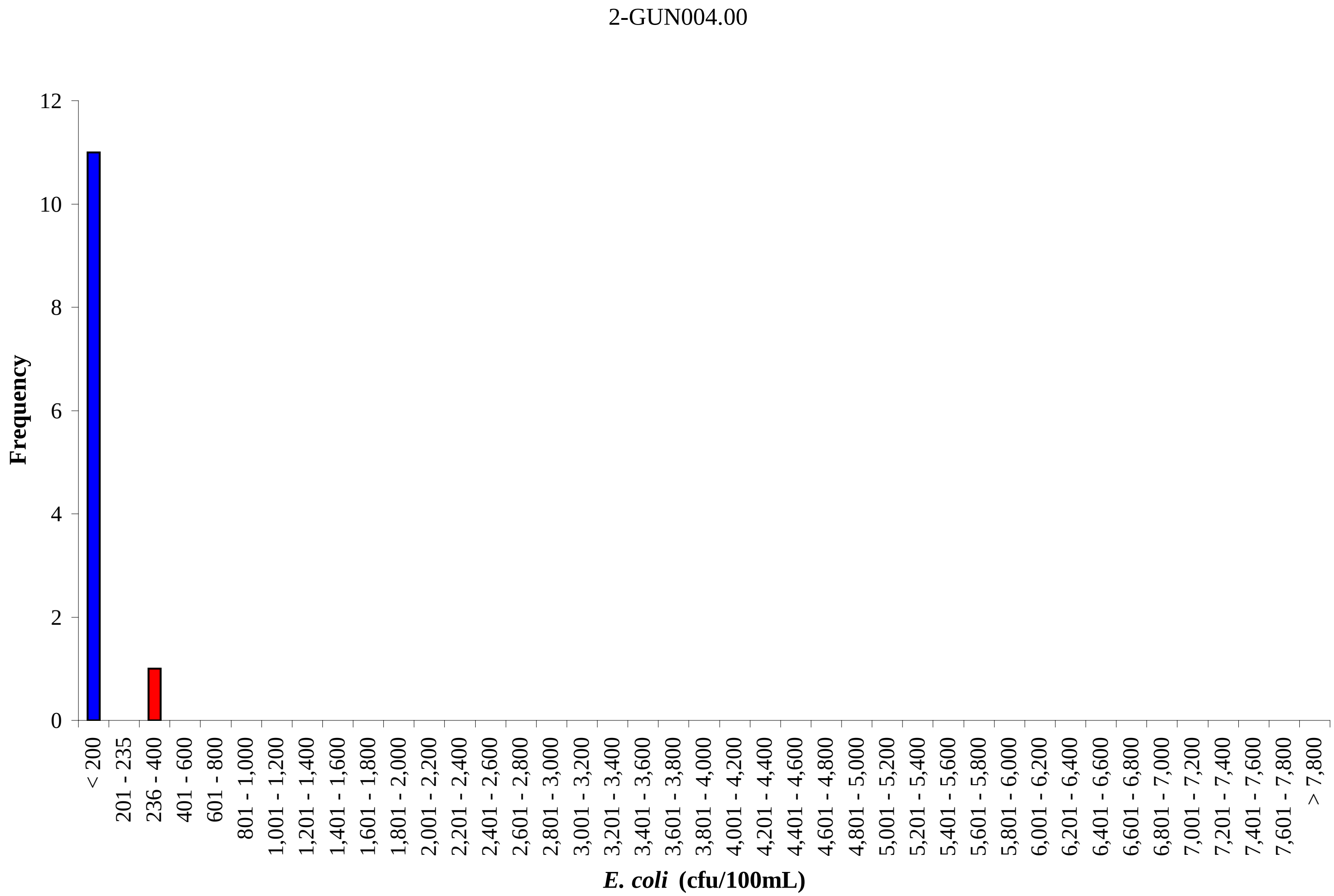

Figure A. 3 Frequency analysis of *E. coli* concentrations at station 2-GUN004.00 in Gunns Run for the period from July 2003 to April 2008.

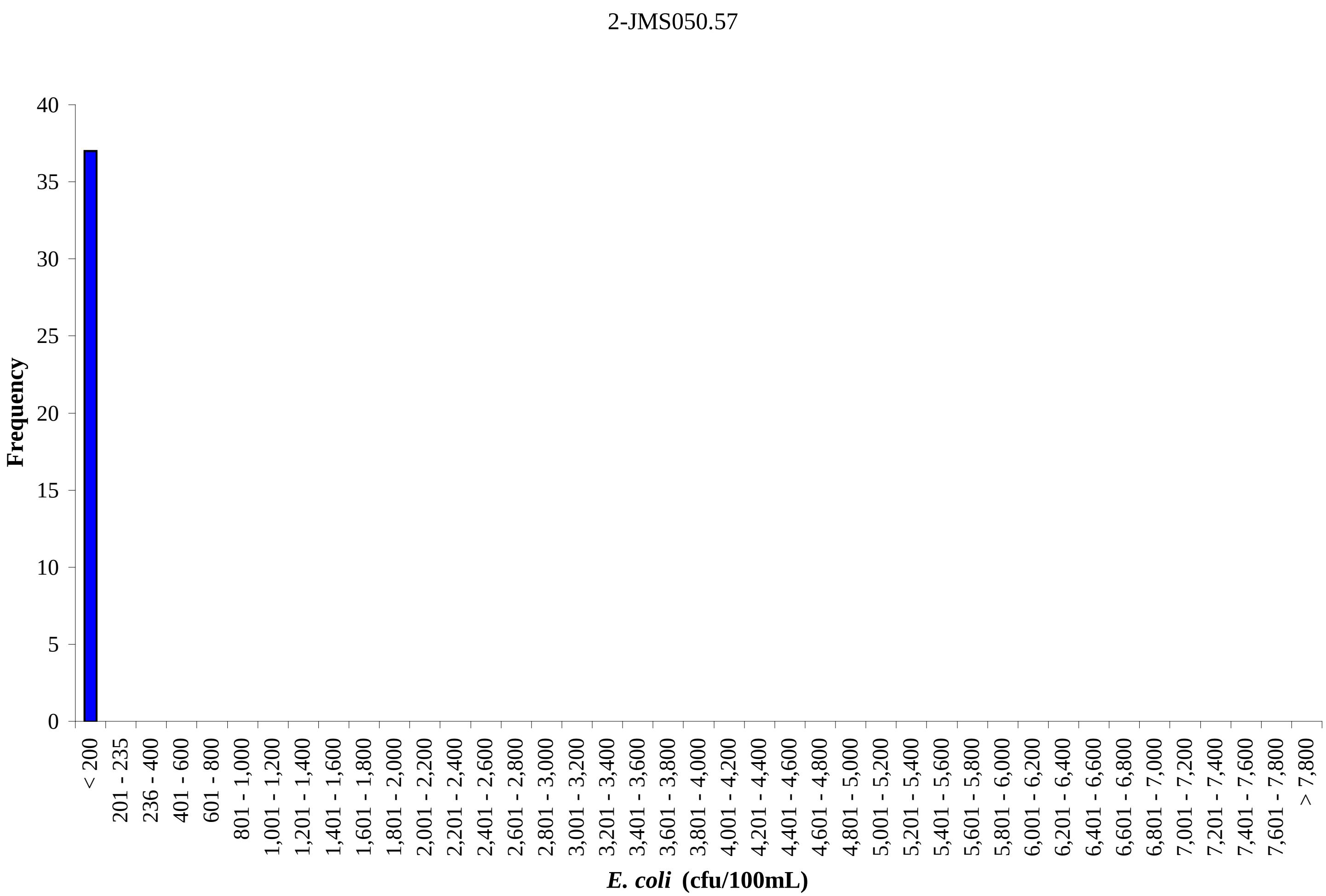

Figure A. 4 Frequency analysis of *E. coli* concentrations at station 2-JMS050.57 in the James River for the period from July 2004 to August 2007.

Figure A. 5 Frequency analysis of *E. coli* concentrations at station 2-JMS052.02 in the James River for the period from June 2007 to December 2010.

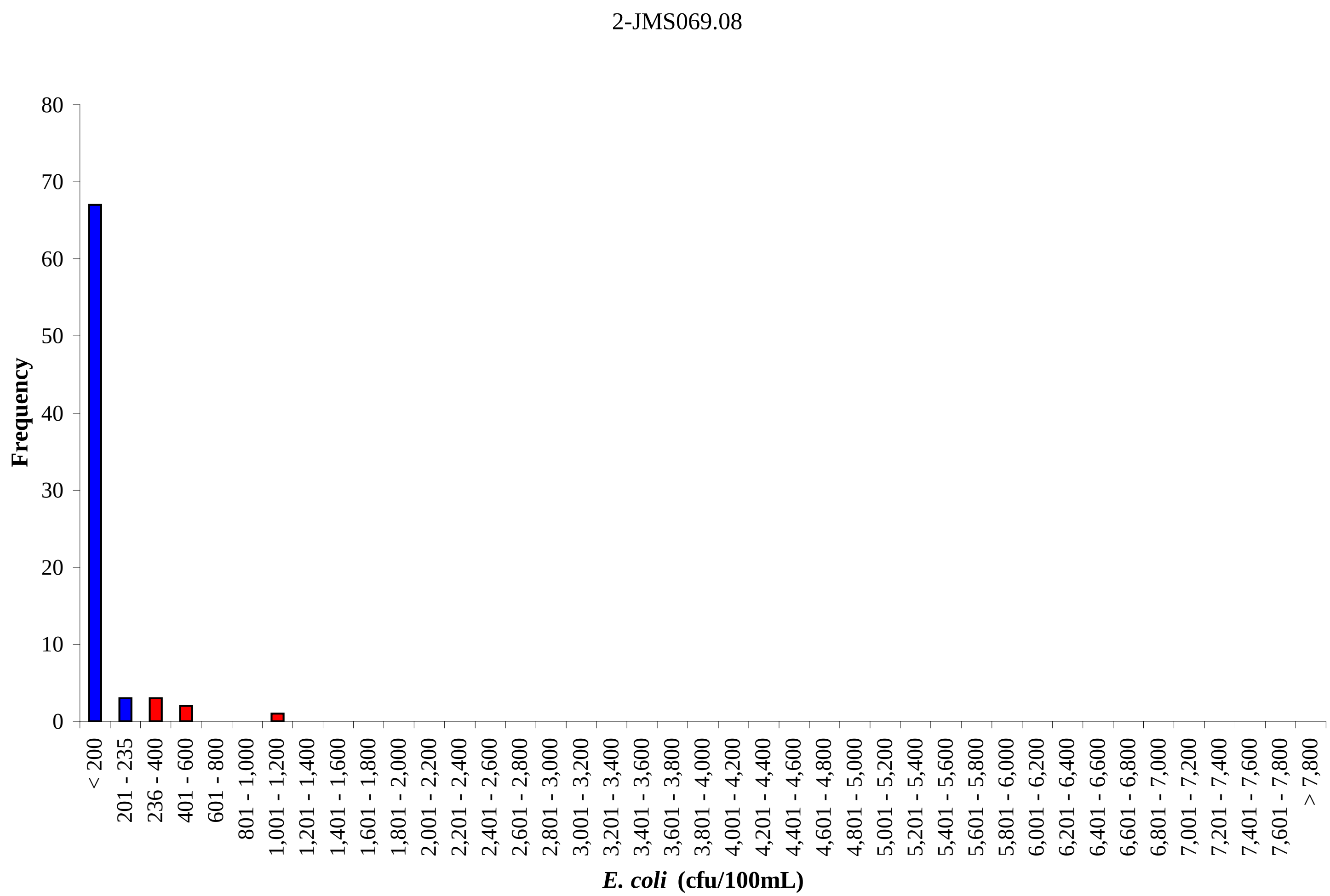

Figure A. 6 Frequency analysis of *E. coli* concentrations at station 2-JMS055.94 in the James River for the period from July 2004 to January 2011.

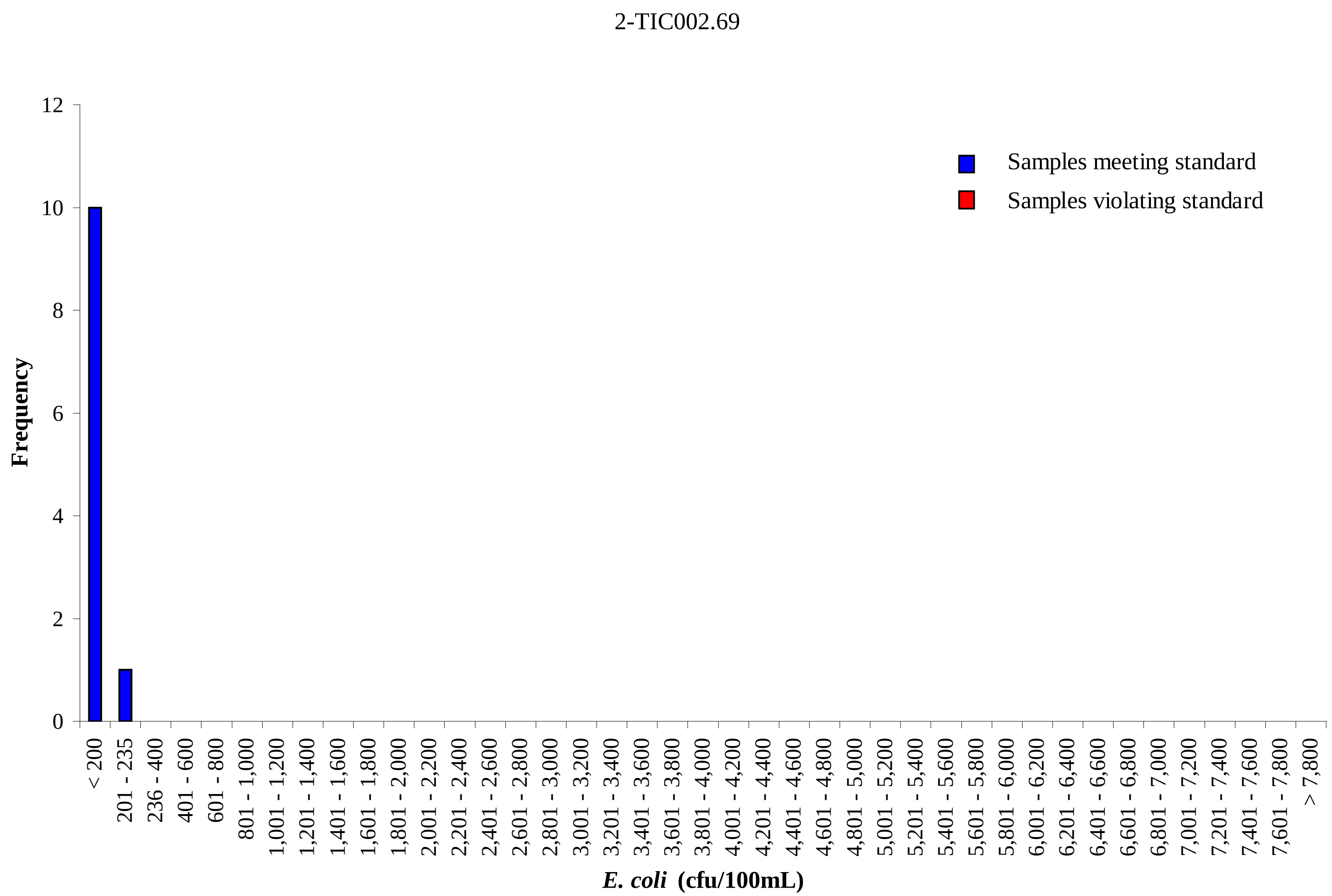

Figure A. 7 Frequency analysis of *E. coli* concentrations at station 2-TIC002.69 in Turkey Island Creek for the period from June 2005 to January 2011.

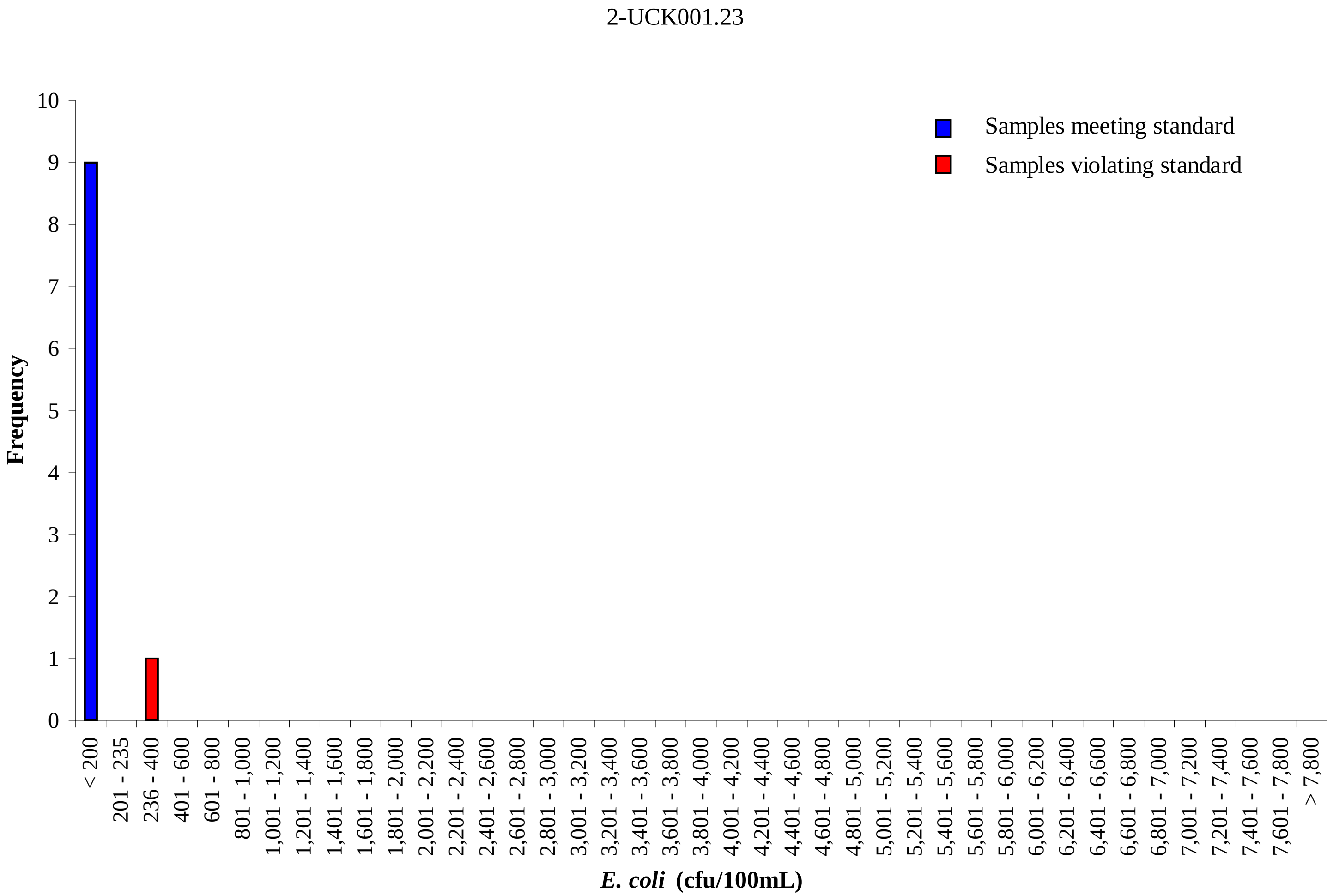

Figure A. 8 Frequency analysis of *E. coli* concentrations at station 2-UCK001.23 in Upper Chippokes Creek for the period from August 2003 to March 2005.

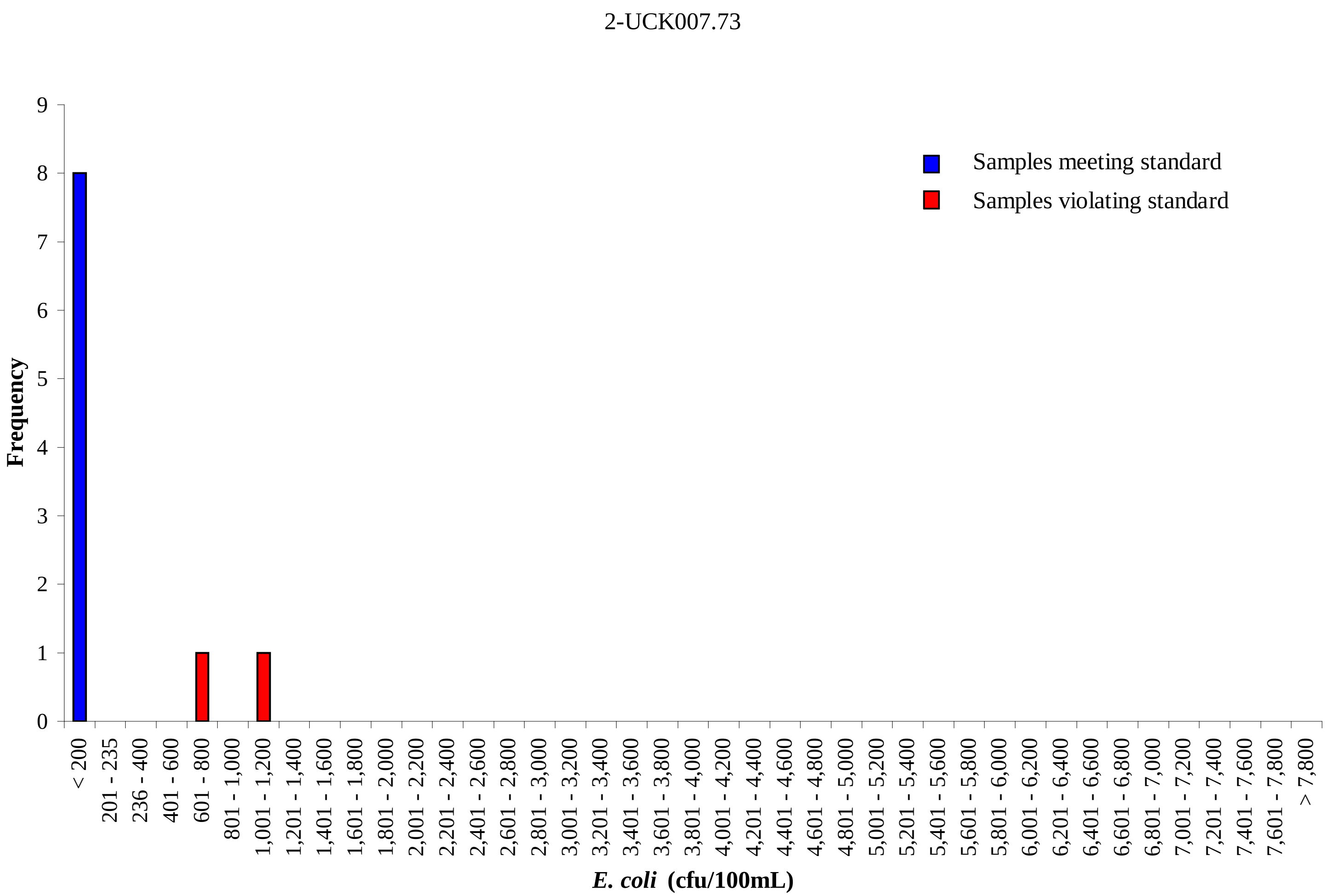

Figure A. 9 Frequency analysis of *E. coli* concentrations at station 2-UCK007.73 in Upper Chippokes Creek for the period from May 2005 to November 2006.

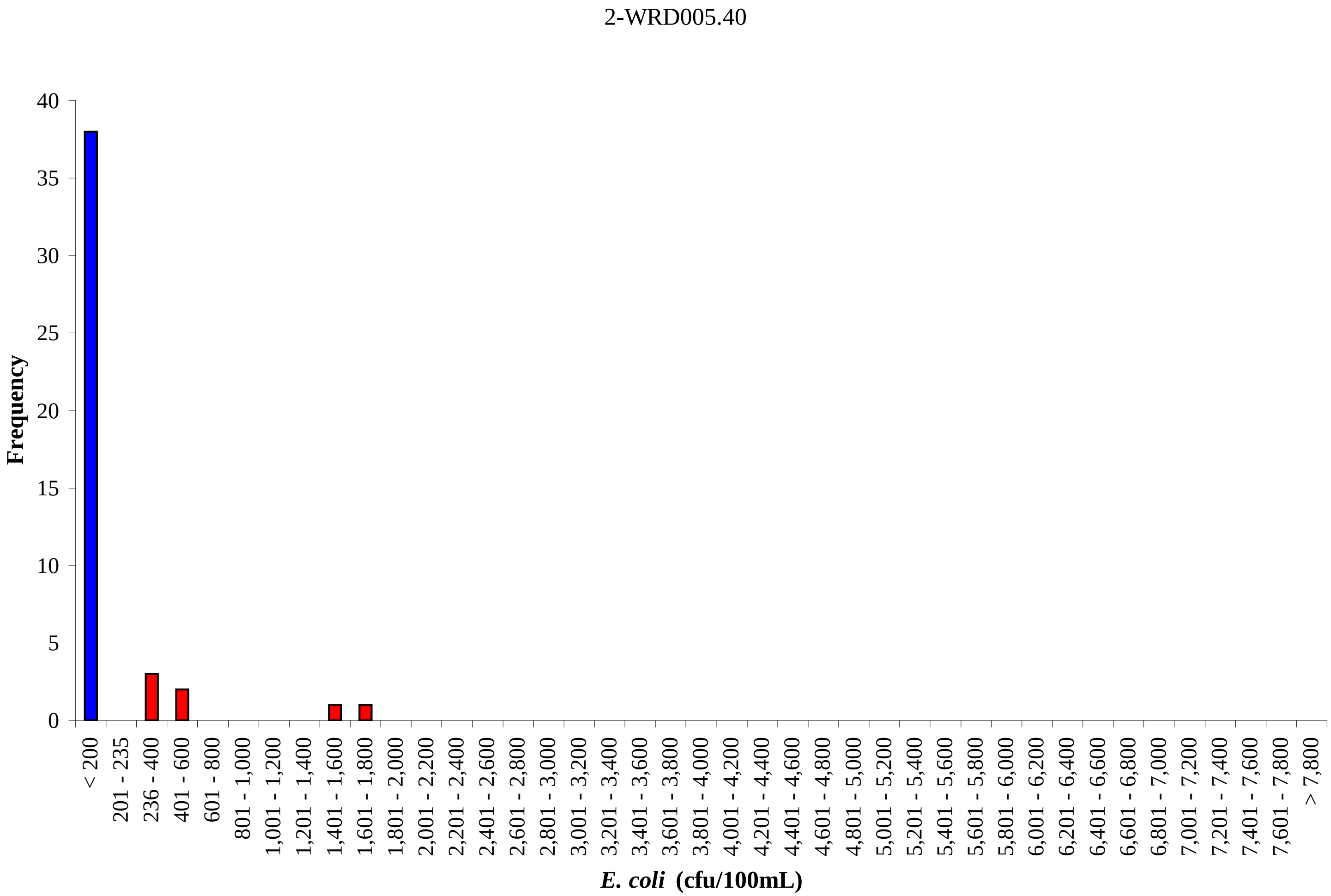

Figure A. 10 Frequency analysis of *E. coli* concentrations at station 2-WLR004.46 in Wards Creek for the period from August 2003 to December 2010.

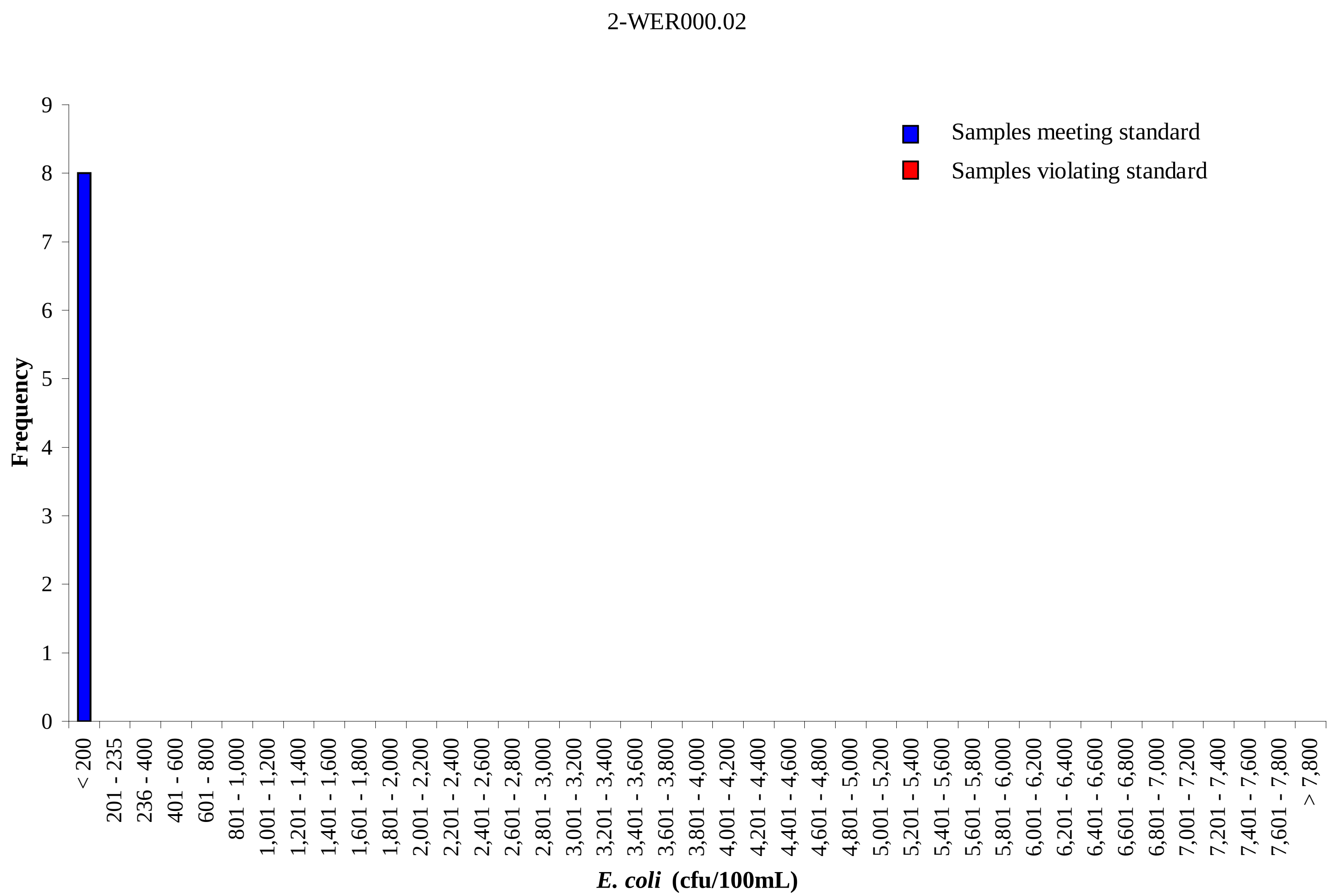

Figure A. 11 Frequency analysis of *E. coli* concentrations at station 2-WER000.02 in West Run for the period from August 2003 to October 2008.

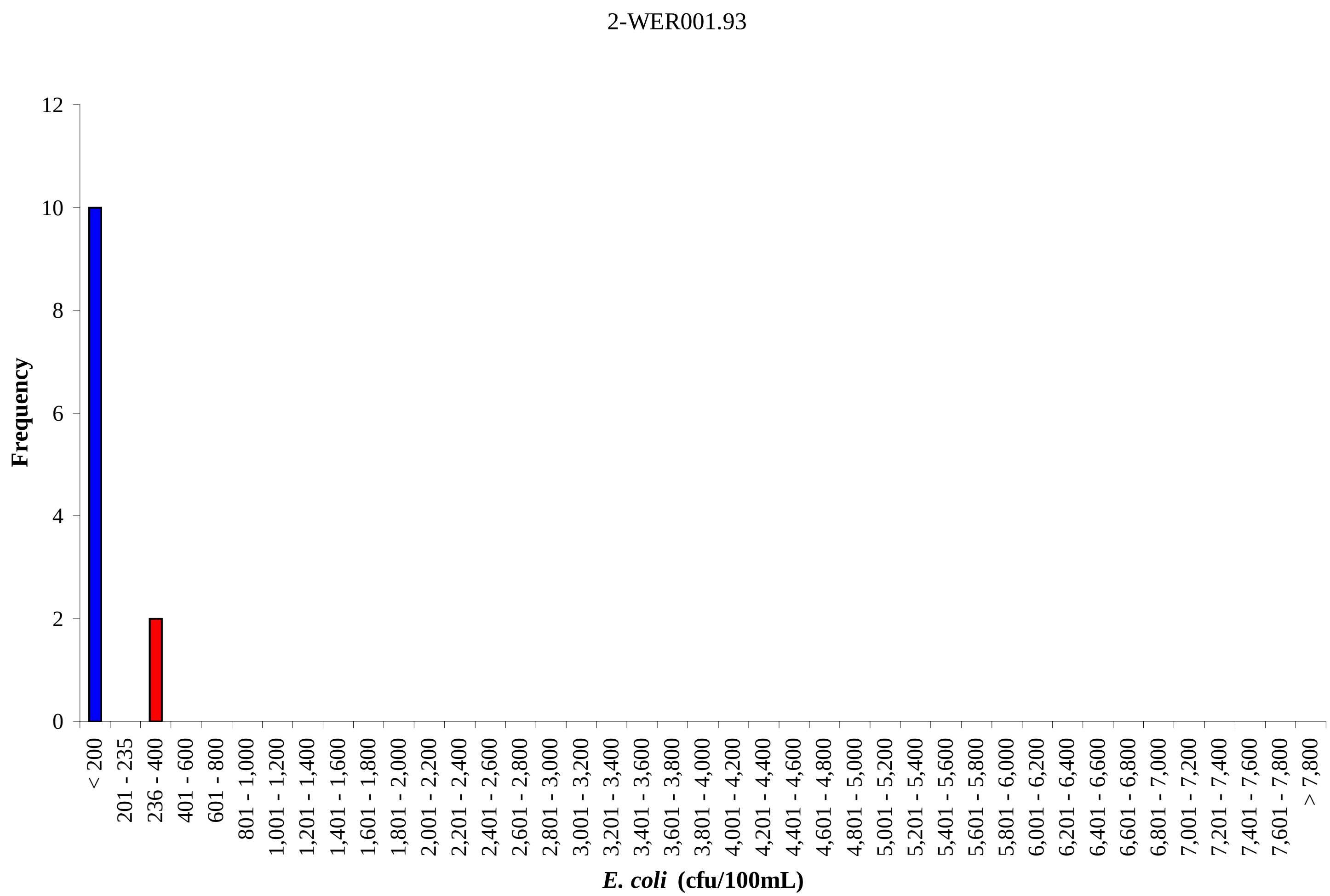

Figure A. 12 Frequency analysis of *E. coli* concentrations at station 2-WER001.93 in West Run for the period from January 2007 to November 2008.

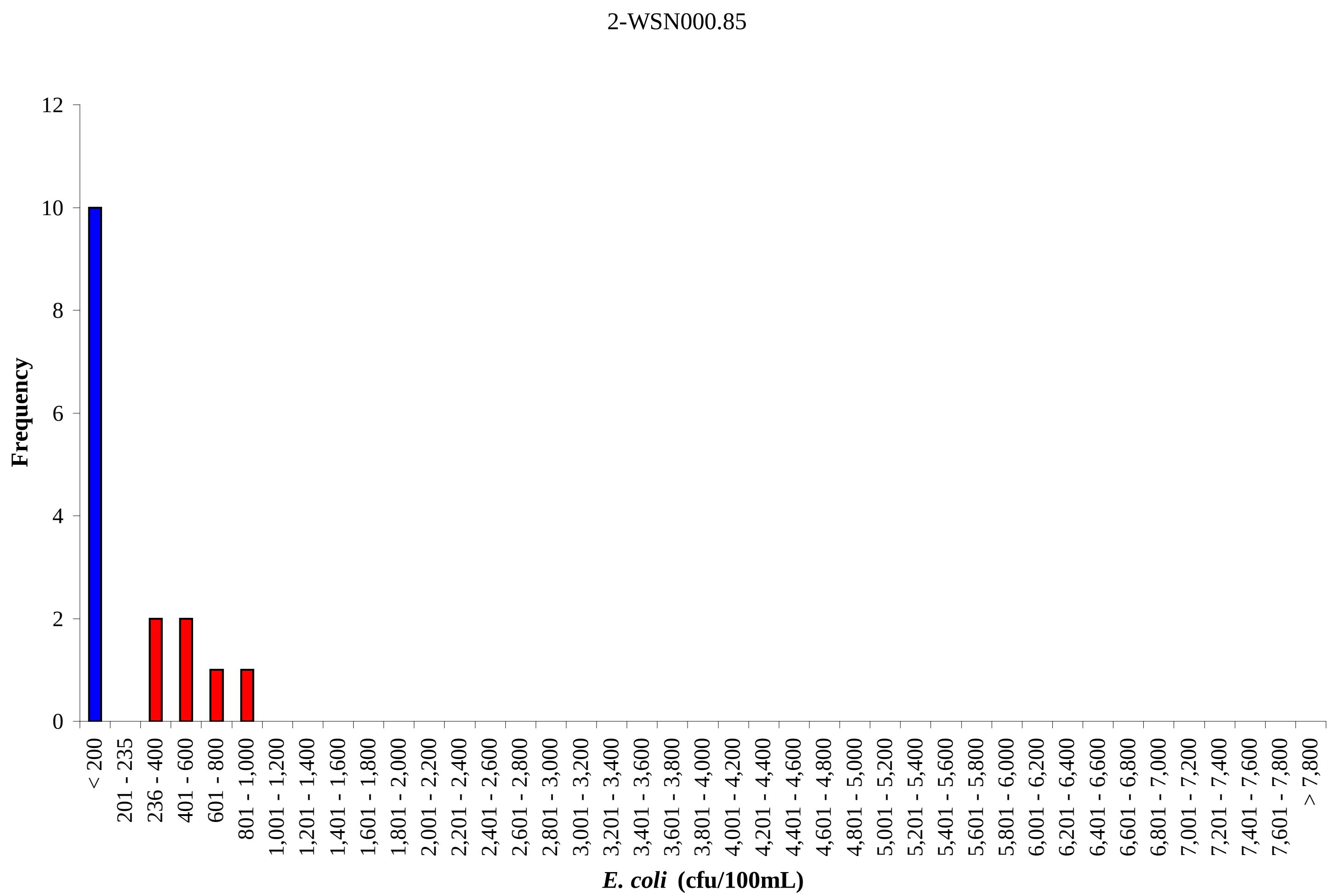

Figure A. 13 Frequency analysis of *E. coli* concentrations at station 2-WSN000.85 in Western Run for the period from May 2004 to November 2006.

APPENDIX B

Bacteria modeling procedure: Linking the sources to the endpoint

Bacteria modeling procedure: Linking the sources to the endpoint

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs in the study area, the relationship was defined through computer modeling based on data collected throughout the watersheds. Monitored flow and water quality data were then used to verify the accuracy of the relationships developed through modeling. There are five basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality.

Modeling Free-flowing Impairments

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate streamflow, overland runoff and to perform bacteria TMDL allocations.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

Modeling the Tidal Impairment

The Steady State Tidal Prism Model, which is used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model the tidally influenced impairment in conjunction with lateral free-flowing impairment creeks and input from upstream James River. The entire length of the James River within the study area is tidally influenced and so are multiple creeks flowing laterally into the James River between Herring Creek upstream, to Upper Chippokes Creek downstream.

MapTech’s implementation of the Tidal Prism Model uses the same basic principle of a control volume with ebb and flood tides based on monitored tide data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody.

Model Setup

Hourly precipitation data was available within the watershed at the Hopewell NCDC Coop station #444101. Missing values were filled using daily precipitation from the Petersburg NCDC Coop station #446656.

Subwatersheds

To adequately represent the spatial variation in the watershed, the study area was divided into forty two (42) subwatersheds (**Figure B. 1**). Seven of those subwatersheds (36 through 42) represent the Turkey Island Creek drainage area that contains Western Run and Crewes Channel impairments. Subwatersheds 1 and 8 through 13 make up NTU 90.2 and subwatersheds 2 through 7 and 14 through 34 up NTU 91.1. The rationale for choosing these subwatersheds was based on the availability of water quality and flow data, the stream network configuration, and the limitations of the HSPF model.

Figure B.1 shows all subwatersheds, which were used to achieve the unified model. **Table B. 1** notes the subwatersheds contained within each impairment, the impaired stream segments, and the outlet subwatershed for each impairment.

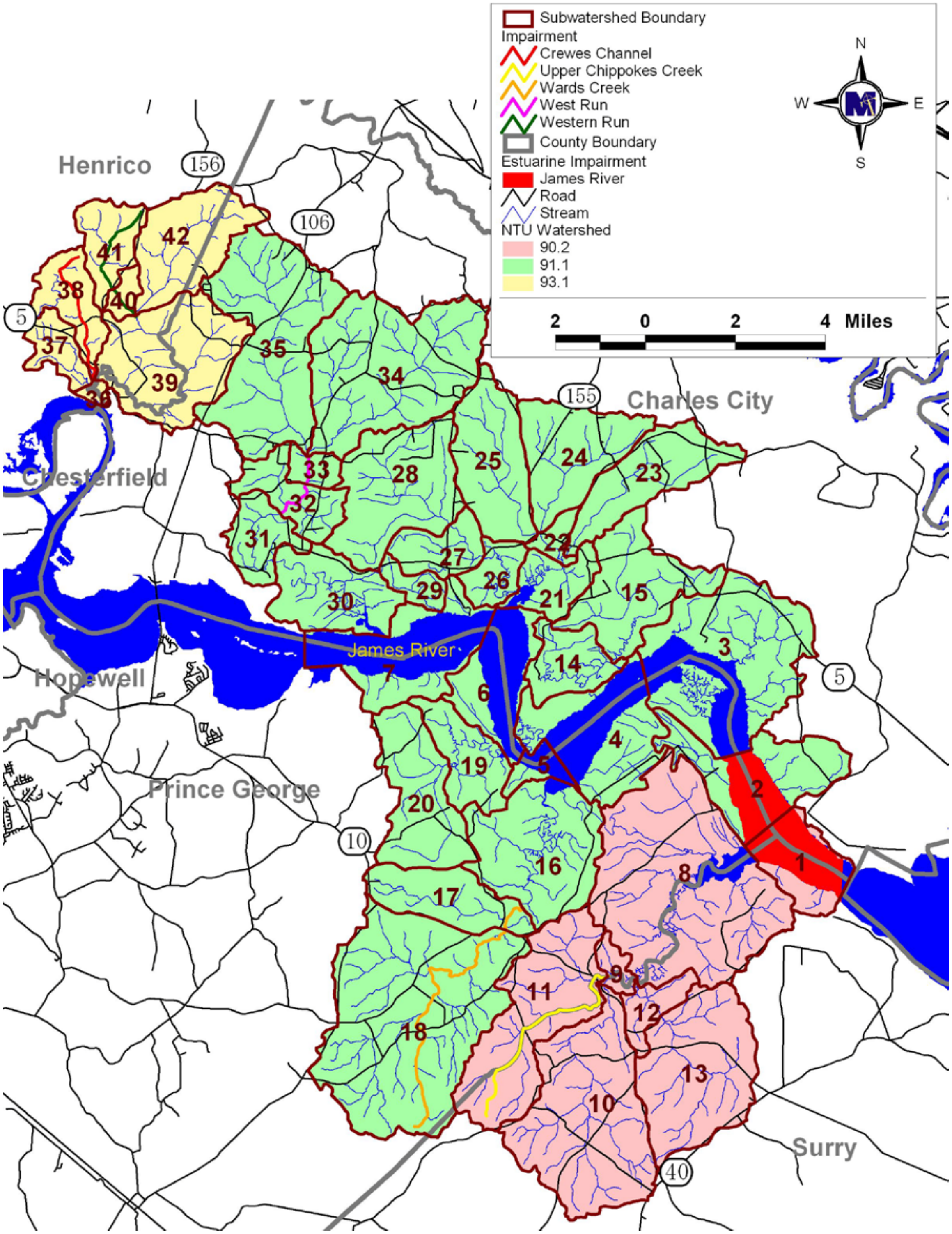

Figure B. 1 All subwatersheds delineated for modeling in the study area.

Table B. 1 Impairments and subwatersheds within the study area.

Impairment	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds within each NTU
Crewes Channel VAP-G02R_CCH01A00	38	38	38
Western Run VAP-G02R_WSN01A00	40,41	40	40,41
West Run VAP-G03R_WER03A00	32,33	32	32,33,34,35
Wards Creek VAP-G04R_WRD01A00	17,18	17	17,18
Upper Chippokes Creek VAP-G04R_UCK01A08	11	11	11
James River VAP-G04E_JMS03A04	1,2	1	1,8,9,10,11,12,13

In an effort to standardize modeling procedures across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

Land Uses

Nine land uses were identified in the watershed. These land uses were obtained by merging different sources including the MRLC land use grid, and aerial photography of the region. The nine land use types are given in **Table B. 2**. Within each subwatershed, up to the nine land use types were represented. Each land use in each subwatershed has hydrologic parameters (*e.g.*, average slope length) and pollutant behavior parameters (*e.g.*, *E. coli* accumulation rate) associated with it. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others vary with the season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

Table B. 2 shows the percentage pervious for each land use as used in modeling the study area. **Table B. 3** shows the breakdown of land uses within the drainage area. Land use distribution within the watershed is shown in **Figure B. 2**.

Table B. 2 Consolidated land use categories for the study area used in HSPF modeling.

TMDL Land use Categories	Pervious / Impervious (%)
Barren	Pervious (90%) Impervious (10%)
Commercial	Pervious (50%) Impervious (50%)
Cropland	Pervious (100%)
Low-Medium Intensity Residential (LMIR)	Pervious (90%) Impervious (10%)
Open Space	Pervious (100%)
Forest	Pervious (100%)
Livestock Access	Pervious (100%)
Pasture	Pervious (100%)
Water	Pervious (100%)
Wetland	Pervious (100%)

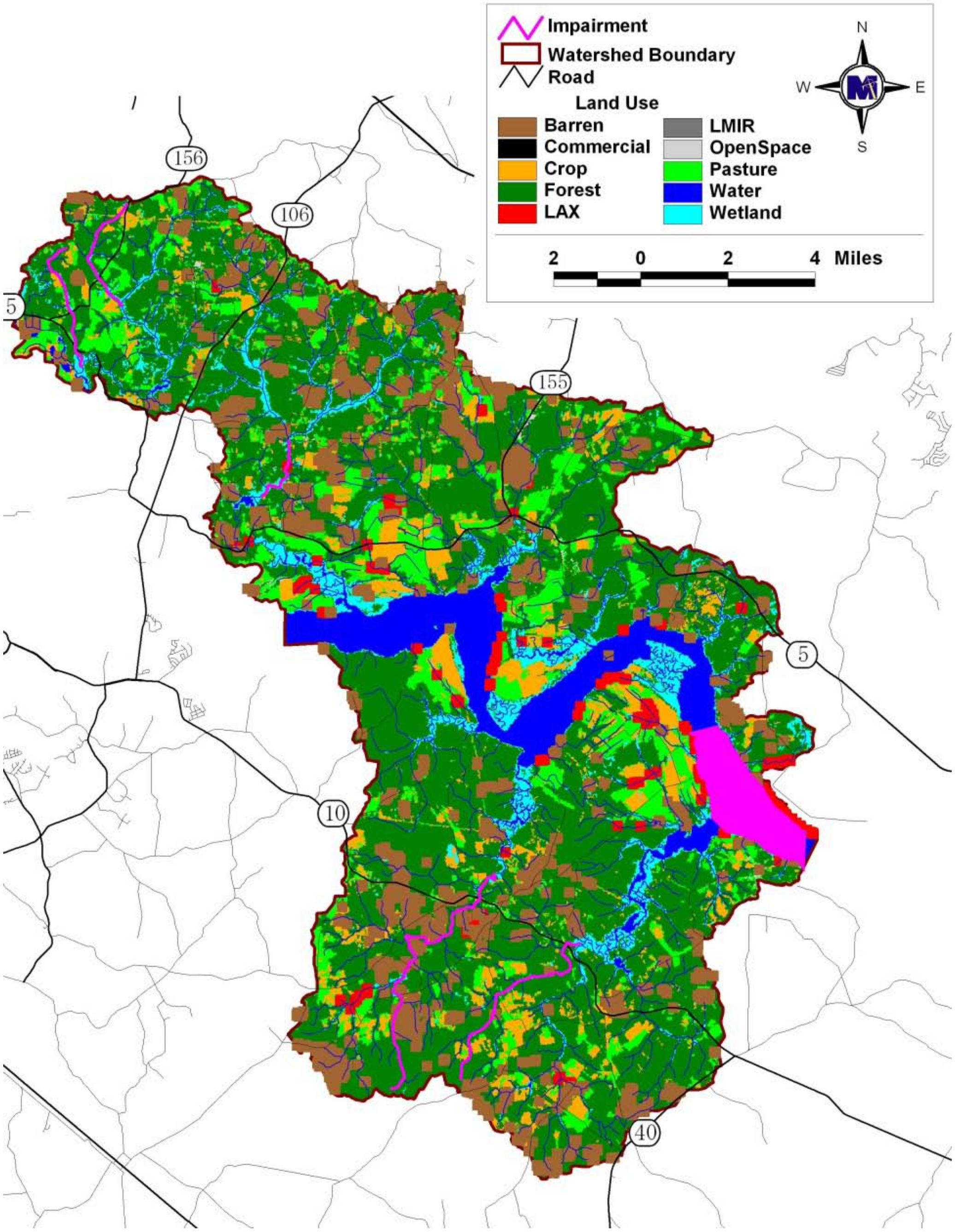

Figure B. 2 Land uses in the study area watershed.

Table B. 3 Area of land use types in acres in the study area.

Impairment	Barren	Commercial	Cropland	Forest	LAX	LMIR	Open Space	Pasture	Water	Wetland	Total Acres
Turkey Island Creek (NTU 93.1)	57.45	0.22	1,108.30	7,488.57	8.82	9.35	21.96	1,978.46	137.04	943.85	11,754.02
Westover to Chippokes Point (NTU 91.1)	1,767.65	0.65	8,206.70	48,668.31	45.92	90.48	246.58	11,545.44	9,303.94	6,296.47	86,172.14
Chippokes Point to Claremont (NTU 90.2)	387.37	0.00	2,907.95	19,541.57	14.84	17.71	75.16	3,082.79	2,129.12	1,487.56	29,644.07

Die-off of fecal bacteria can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.,* dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal bacteria entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). This data are entered into HSPF via the Hydraulic Function Tables (F-tables). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and discharge (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume in the reach, and is reported in acre-feet. The discharge is simply the stream outflow, in cubic feet per second.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2012) and Digital Elevation Models (DEM) data was used. The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the watershed. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each subwatershed outlet. A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet (**Figure B. 3**).

Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example of an F-table used in HSPF is shown in **Table B. 4**.

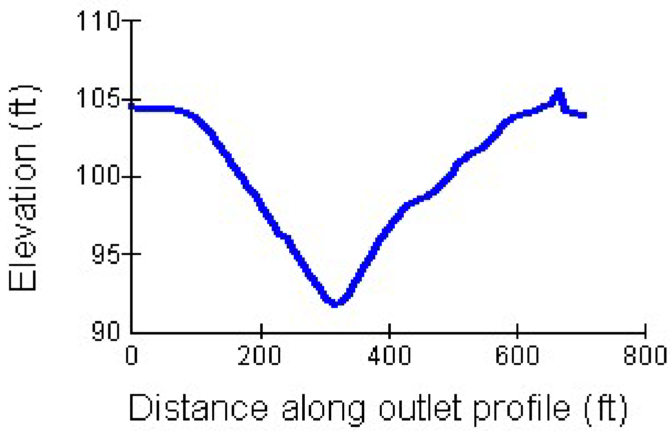

Figure B. 3 Stream profile representation in HSPF.

Table B. 4 Example of an F-table calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
3.28	0.71	1.41	17.07
6.56	1.89	5.15	45.23
9.84	2.54	12.18	85.02
13.12	4.77	24.80	152.82
16.40	56.55	77.51	637.72
19.68	1,047.22	1,635.10	18,846.85
22.96	2,875.31	7,405.99	69,827.77
26.24	3,495.32	18,464.40	133,806.76
29.52	4,426.89	31,720.10	160,393.97

Selection of Representative Modeling Periods

The selection of a representative modeling period takes into consideration historical records of precipitation, flow, and water quality. Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions.

The modeling period was selected to include the VADEQ assessment period from July 1992 through December 2010 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002, 2004, 2006, 2008, and 2010 Section 303(d) lists. The *E. coli* concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of *E. coli* coliform were recorded in all flow regimes (Figure B.4 through Figure B.17), thus it was concluded that the critical hydrological condition included a wide range of wet and dry seasons. Bacteria model calibration and validation were conducted for the period of October 2003 to September 2009 based on availability of monitored data.

Bacteria TMDL Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the study area is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the study area are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include nonpoint sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A description of the data used in these analyses is shown in Chapter 2. Graphical analyses of fecal bacteria concentrations and flow duration intervals showed that water quality standard violations occurred at nearly every flow interval at the monitoring locations within the study area (**Figure B. 4 - Figure B. 17**). This demonstrates that all flow regimes should be represented in the allocation modeling time period. Therefore, to account for critical conditions for bacteria in the watershed, the allocation modeling period is selected to coincide with the hydrologic validation period (2006 to 2009) since this period was selected to include both low and high flow conditions. Both the hydrologic calibration and validation periods include wet and dry years based on the analyses of historical data. However, the hydrologic validation period was chosen as the allocation modeling period since this period coincides with available biosolids data which was not available during hydrologic calibration period.

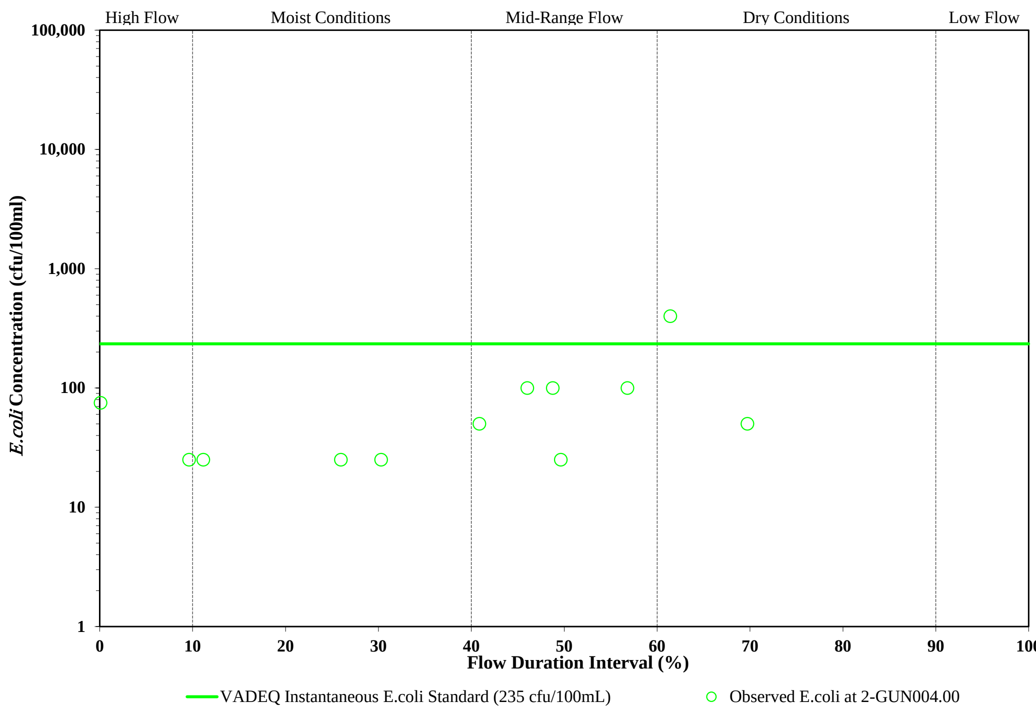

Figure B. 4 *E. coli* concentrations-duration at 2-GUN004.00 on Gunns Run.

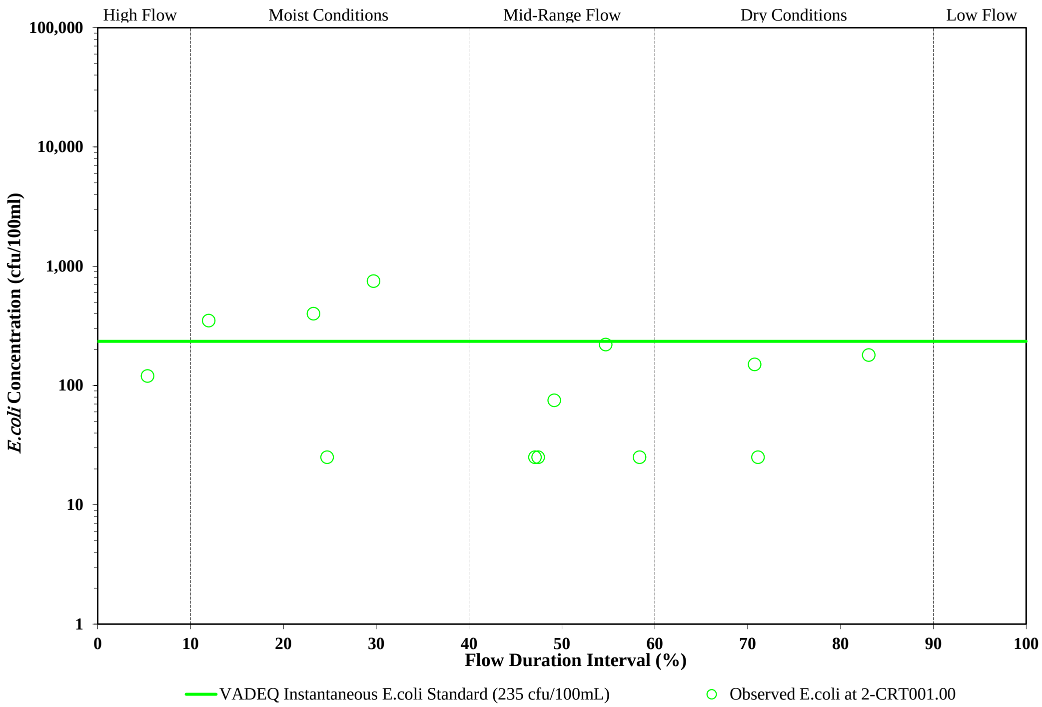

Figure B. 5 *E. coli* concentrations at 2-CRT001.00 on Courthouse Creek.

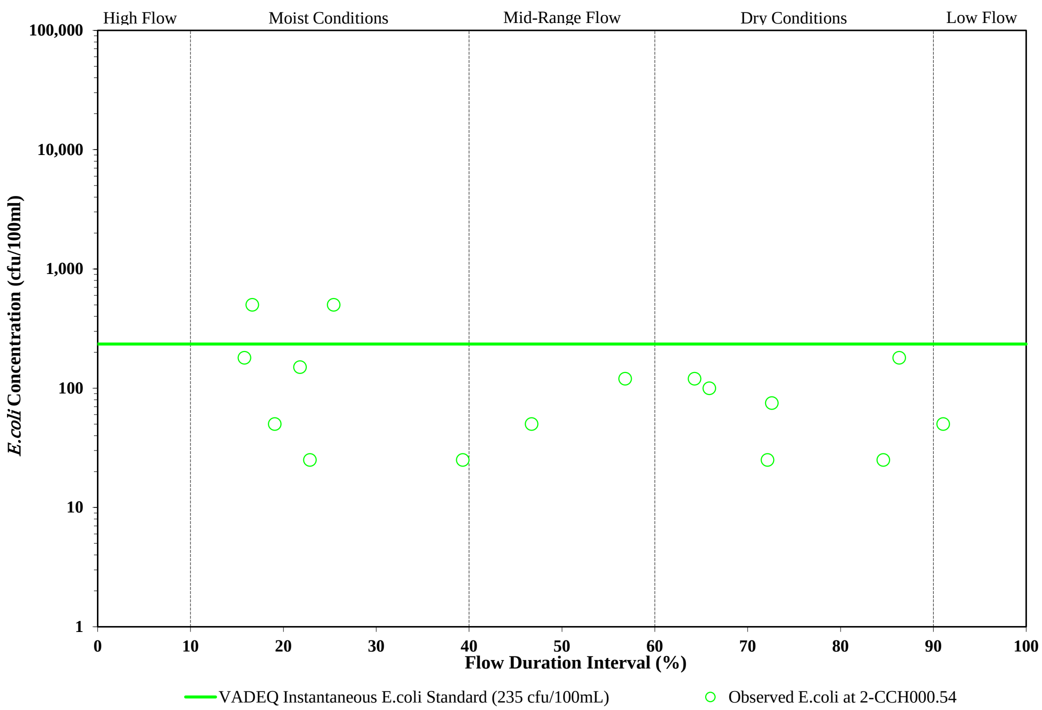

Figure B. 6 *E. coli* concentrations-duration at 2-CCH000.54 on Crewes Channel.

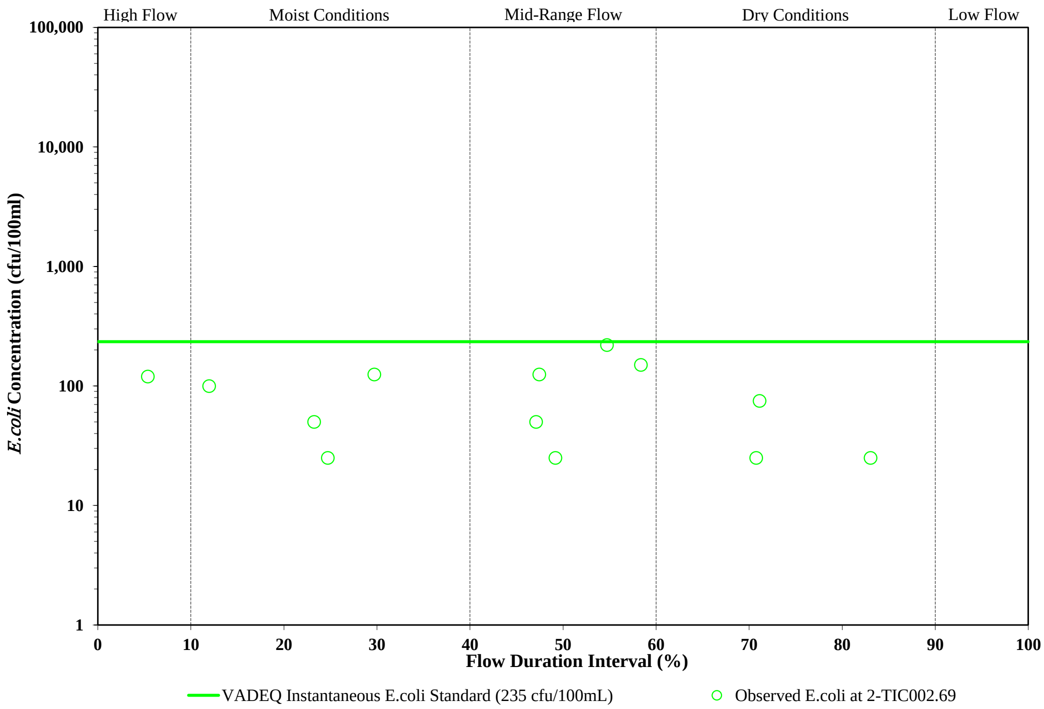

Figure B. 7 ***E. coli* concentrations-duration at 2-TIC002.69 on Turkey Island Creek.**

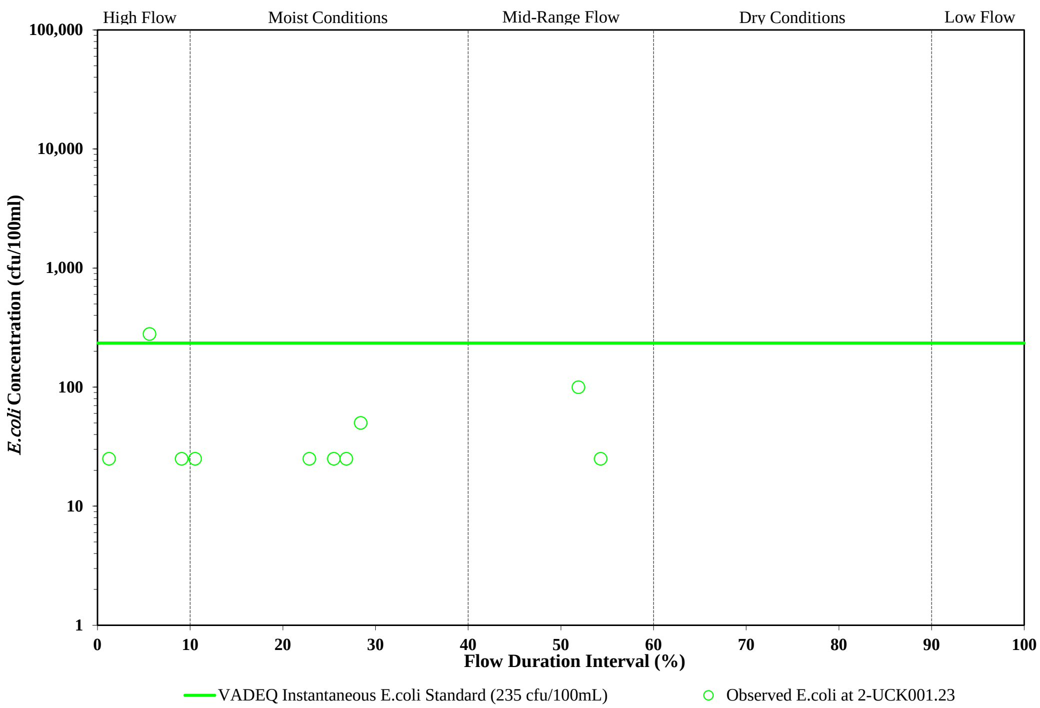

Figure B. 8 ***E. coli* concentrations-duration at 2-UCK001.23 on Upper Chippokes Creek.**

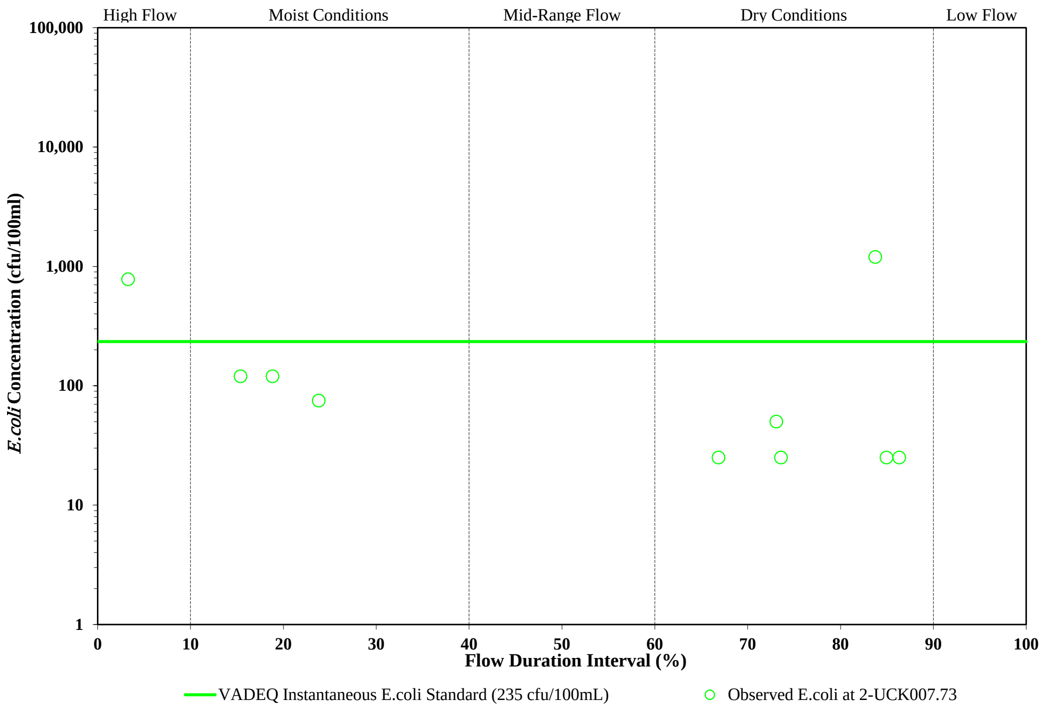

Figure B. 9 ***E. coli*** **concentrations-duration at 2-UCK007.73 on Upper Chippokes Creek.**

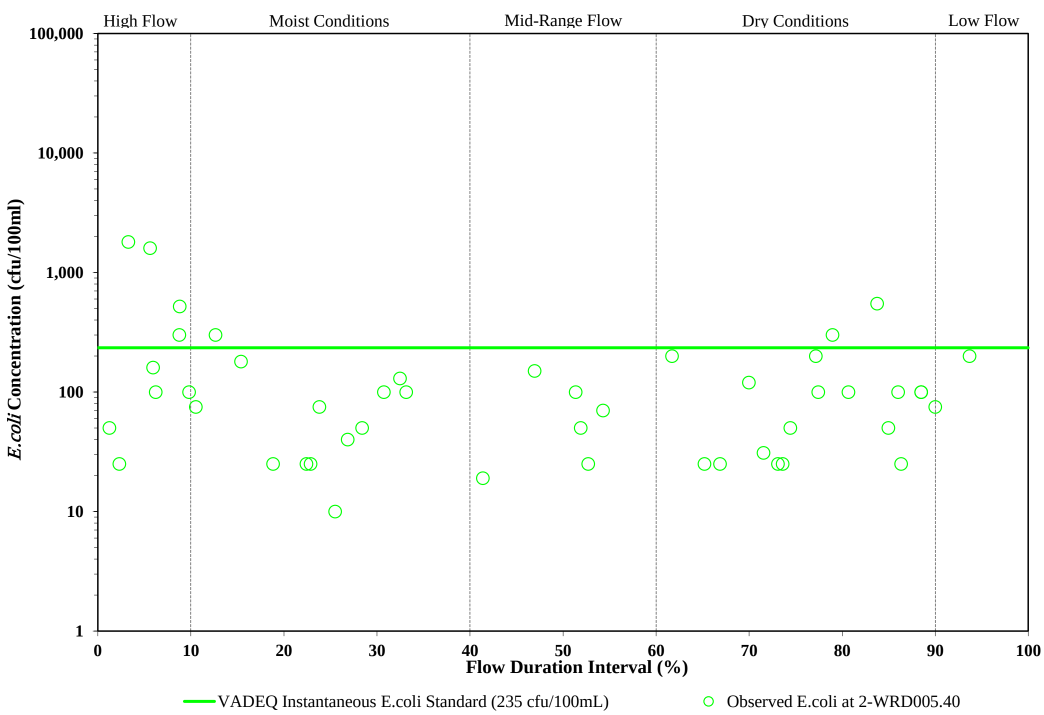

Figure B. 10 ***E. coli*** **concentrations-duration at 2-WRD005.40 on Wards Creek.**

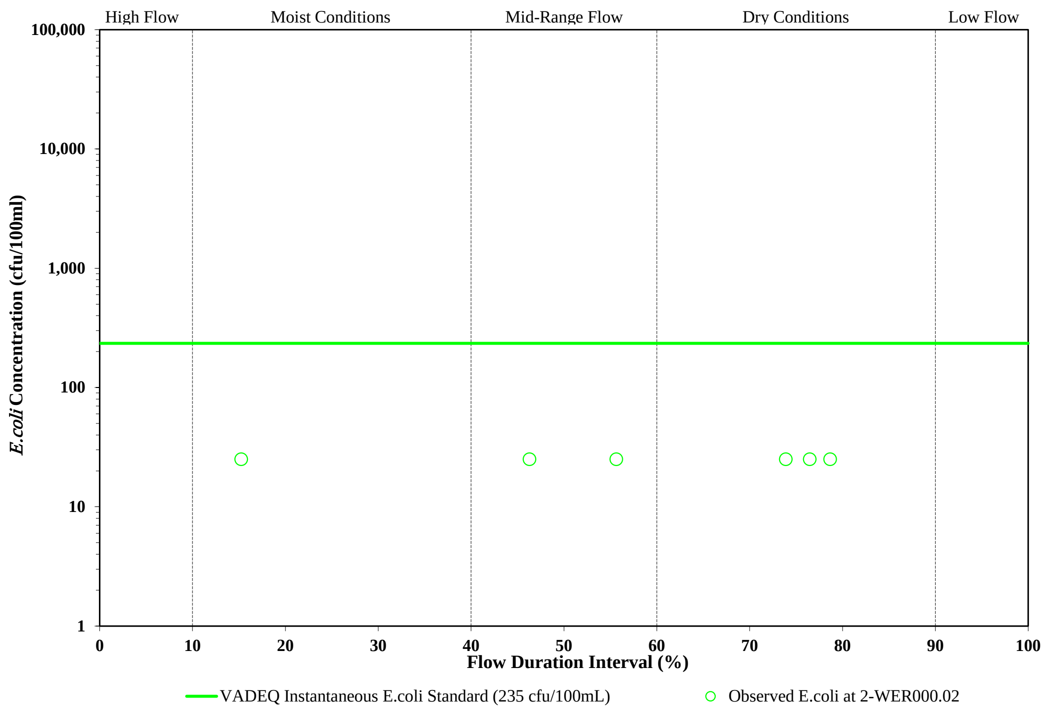

Figure B. 11 *E. coli* concentrations-duration at 2-WER000.02 on West Run.

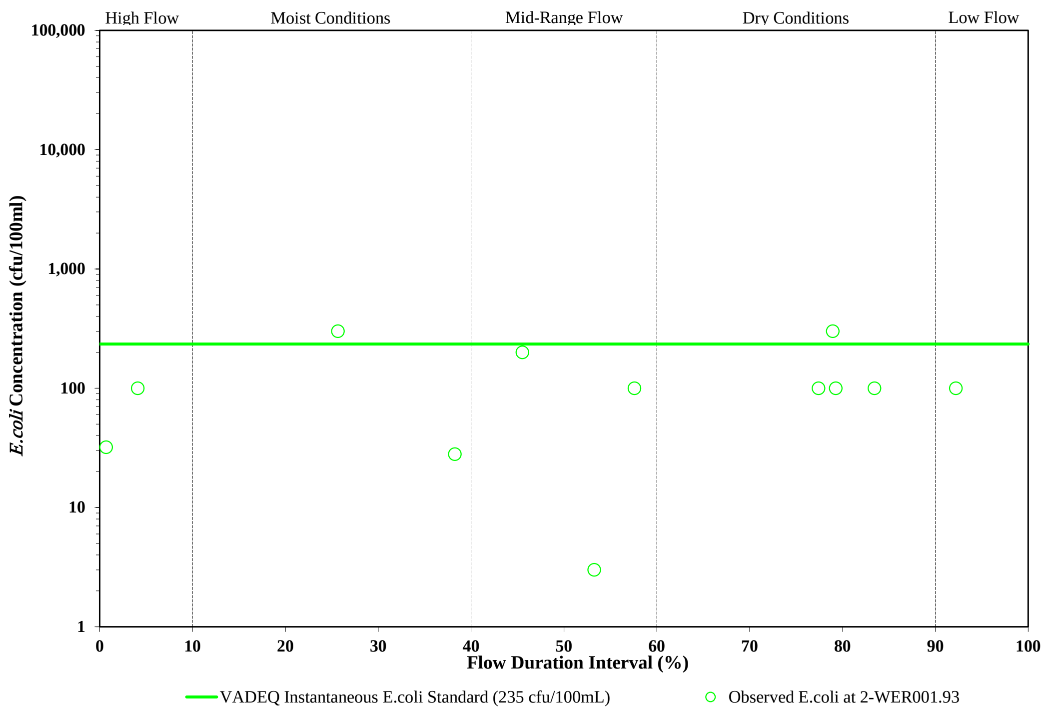

Figure B. 12 *E. coli* concentrations-duration at 2-WER001.93 on West Run.

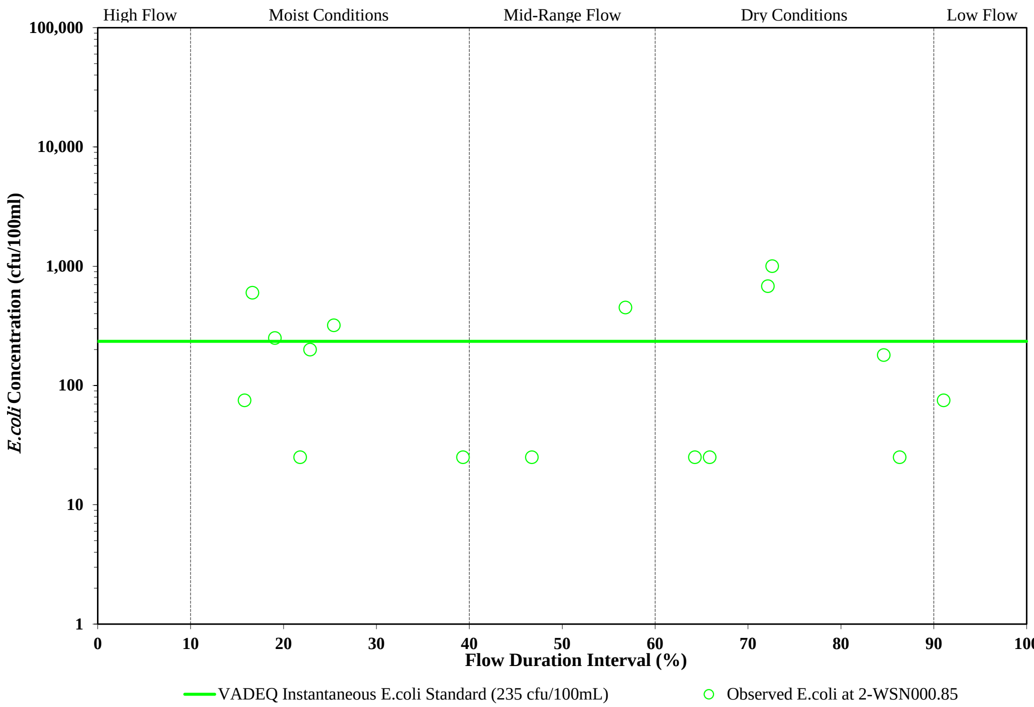

Figure B. 13 ***E. coli*** **concentrations-duration at 2-WSN000.85 on Western Run.**

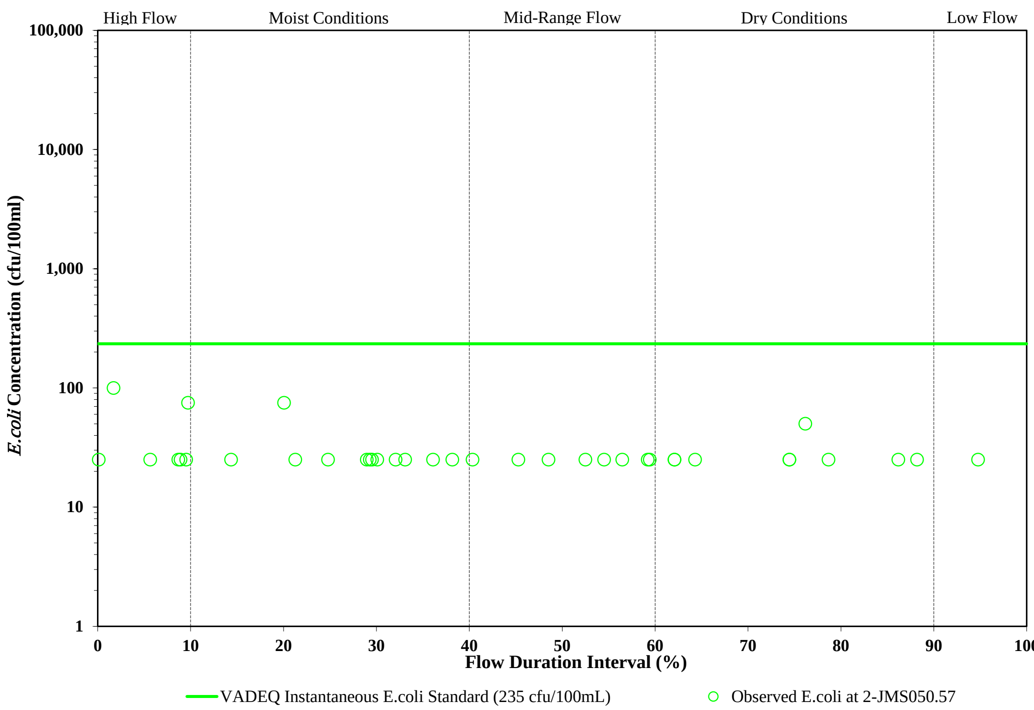

Figure B. 14 ***E. coli*** **concentrations-duration at 2-JMS050.57 on the James River.**

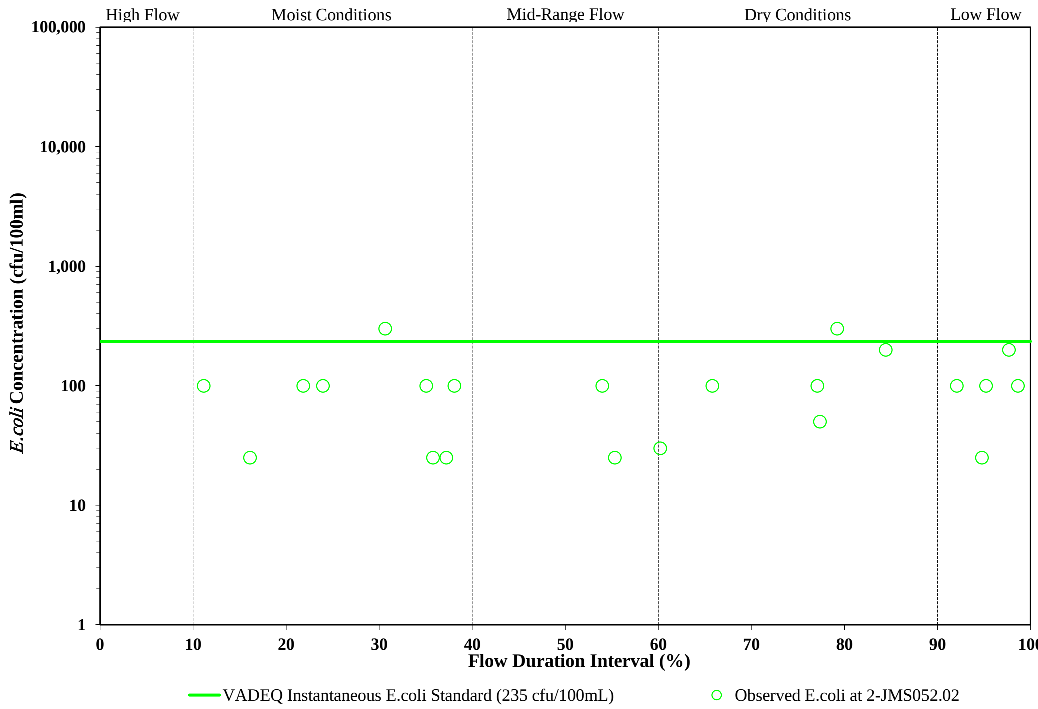

Figure B. 15 ***E. coli*** **concentrations-duration at 2-JMS052.02 on the James River.**

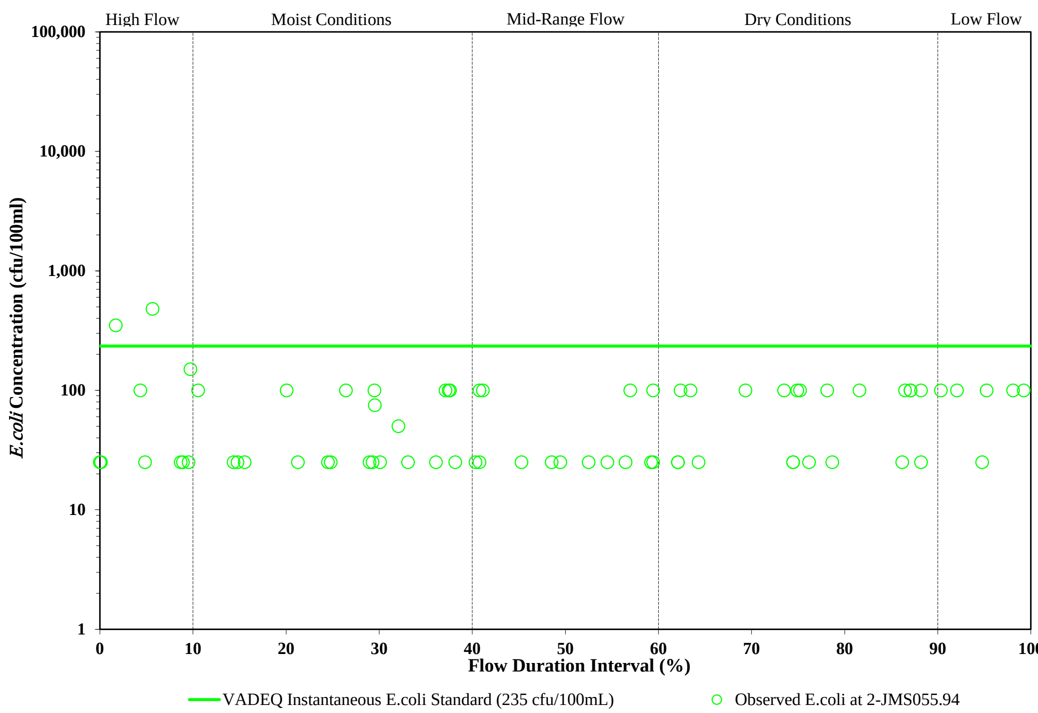

Figure B. 16 ***E. coli*** **concentrations-duration at 2-JMS055.94 on the James River.**

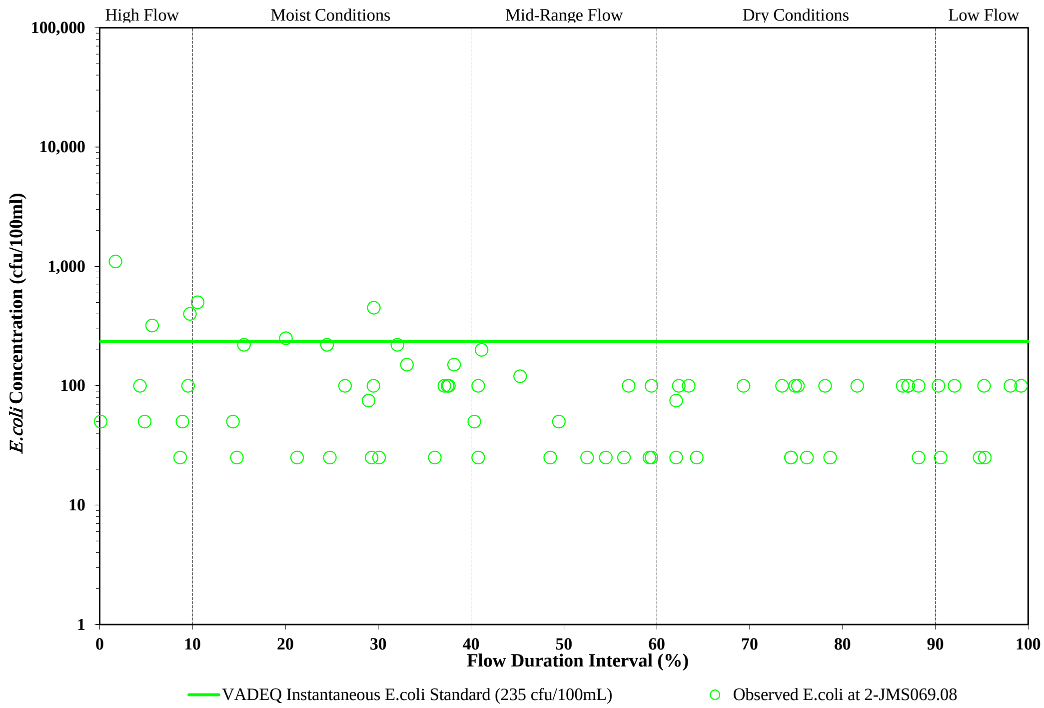

Figure B. 17 ***E. coli*** **concentrations-duration at 2-JMS069.08 on the James River.**

Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different estimates were used when necessary. Data were obtained for the appropriate timeframe for water quality calibration and validation. Data representing 2012 were used for the allocation runs in order to represent current conditions.

Permitted Sources

Six facilities exist within the watershed that are permitted thorugh the Virginia Pollutant Discharge Elimination System (VPDES) and permitted to discharge bacteria into surface waters at the standard (Tables 3.1 and 3.2). When available, during water quality calibration and validation phase of the modeling effort, observed discharge rate and bacteria content data provided by DEQ was used. During the allocation phase of modeling, the design flow was used along with a fecal coliform concentration of 200 cfu/100 mL to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels (**Table B. 5**).

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

Table B. 5 Flow rates and bacteria loads used to model VADEQ active permitted point sources in the study area.

VADEQ Permit Number	Facility Name	Allocation	
		Flow Rate (Million Gallon per Day)	Bacteria Concentration (cfu/100 mL)
			Fecal Coliform Geometric Mean Standard[1]
VA0060585	Charles City Administration Building	0.0045	200
VA0021261	Ruthville Community Center WWTP	0.01	200
VA0079057	Sign Post Estates WWTP	0.072	200
VA0086673	Charles City County Schools WWTF	0.025	200
VAG404206	Residence	0.001	200
VAG404253	Farm	0.001	200

[1] Fecal coliform standard is used since fecal colifom is modeled and not *E. coli* as explained in Chapter 5's introduction.

Private Residential Sewage Treatment

The number of septic systems in the study area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2010) with the subwatersheds. Initial estimates were enhanced with county housing data when available and verified by state agencies (Section 3.2.1). During allocation runs, the number of households was projected to 2012, based on current growth rates (USCB, 2010) resulting in 3,192 septic systems, of which, 105 were assumed to be failing for part of the year and 21 straight pipes (Table 3.4).

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. The initial estimates of the number of failing septic systems was based on the assumption that each septic systems fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with regions Health Departments and feedback was obtained and used in adjusting numbers. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

Straight pipes were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Initial estimates obtained using this method were reduced considerably based on feedback from the regions Health Departments. The loadings from straight pipes were modeled in the same manner as direct discharges to the stream.

Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock populations were estimated for each water quality modeling period (calibration/validation/allocation). The numbers are based on data provided by Virginia Agricultural Statistics (VASS), with values updated and discussed by VADCR, NRCS and SWCDs as well as taking into account growth rates in these counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1999; VASS, 2005). For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams. The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

Land Application of Collected Manure

The average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.2.4. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. Finally, values for the percentage of loafing lot waste collected were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.10). Stored waste was spread on pasture and cropland. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled “Modeling Cattle Stream Access” conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR (MapTech, 2002). The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horses, sheep) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land was area-weighted.

Direct Deposition to Streams

The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in “stream access” areas was calculated based on the “Modeling Cattle Stream Access” study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the “stream access” land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

Biosolids

Investigation of VADEQ data indicated that biosolids applications have occurred within the study area. Class B biosolids are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. Records of biosolids application location, timing and quantity were available, enabling the water quality modeling to be carried out in an “as applied” fashion, wherein the water quality model received land based inputs of biosolids loads on the day in which they actually occurred. During model runs, biosolids were modeled as having a fecal concentration of 157,835 cfu/g, the mean value of measured biosolids concentrations observed in several years of samples supplied by VADEQ for sources applied during 2001 to 2011. Applications were modeled as being spread onto the land surface over a six-hour period on the date of reported application. An assumption of proper application was made, wherein no biosolids were modeled as being spread in stream corridors.

Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.5). An example of one of these layers is shown in **Figure B. 18**. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

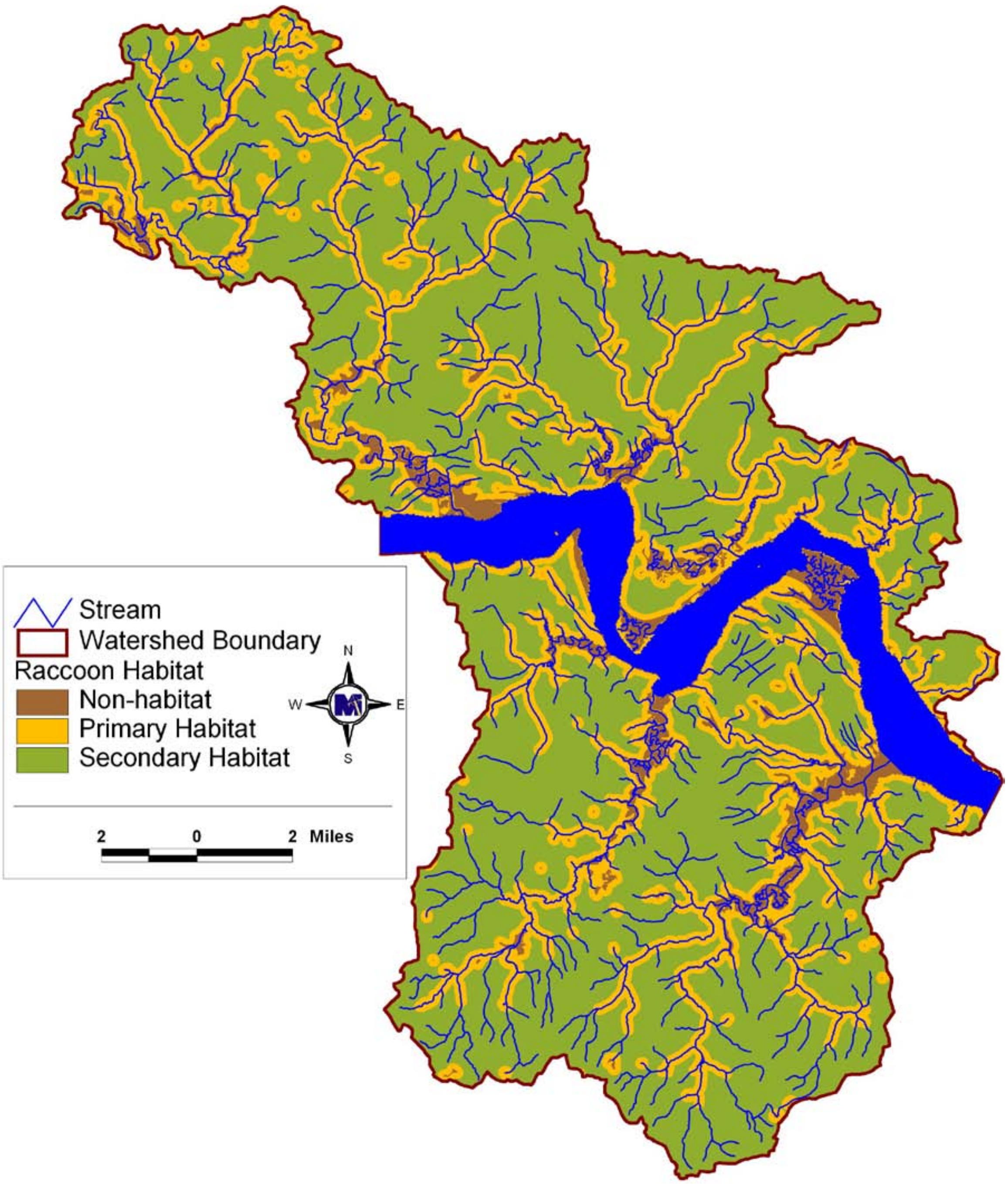

Figure B. 18 Example of raccoon habitat layer in the study area, as developed by MapTech.

For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.15). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams.

Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.2.3. Waste from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 2000 Census (USCB, 1990 and USCB, 2000). The number of animals per subwatershed was determined by multiplying the number of households by the pet population density. The amount of fecal coliform deposited daily by pets in each subwatershed was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected to 2012.

Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in **Table B. 6**, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value, and the model was run for water years 2006-2009. Where an increase of 50% exceeded the maximum value for the parameters, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration), LZSN (Lower Zone Storage), and by UZSN (Upper Zone Storage), which governs surface transport, LZETP (Lower Zone Evapotranspiration), which affects soil moisture and AGWRC (Groundwater Recession Rate). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the *Low Flows* and *Summer Flow Volume* statistics) were AGWRC (Groundwater Recession Rate), LZETP, KVARY (Groundwater Recession Flow), INFILT, and CEPSC (Interception Storage Capacity). The responses of these and other hydrologic outputs are reported in **Table B. 7**.

Table B. 6 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	8.0
INFILT	Soil Infiltration Capacity	in/hr	0.042 – 0.2327
BASETP	Base Flow Evapotranspiration	---	0.05 - 0.05
INTFW	Interflow Inflow	---	2.0 - 2.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.1 - 0.1
AGWRC	Groundwater Recession rate	---	0.94
KVARY	Groundwater Recession Flow	1/in	1.0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.01-0.2
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.35-1.04
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.01-0.40

Table B. 7 HSPF Sensitivity analysis results for hydrologic model parameters for the study area.

		Percent Change In							
Model Parameter	**Parameter Change (%)**	**Total Flow**	**High Flows**	**Low Flows**	**Winter Flow Volume**	**Spring Flow Volume**	**Summer Flow Volume**	**Fall Flow Volume**	**Total Storm Volume**
AGWRC[1]	0.85	1.17	11.03	-58.16	-1.66	1.79	2.58	1.81	1.17
AGWRC[1]	0.92	0.32	2.94	-18.67	-0.58	0.43	0.68	0.68	0.32
AGWRC[1]	0.96	-0.39	-3.38	23.72	0.80	-0.31	-0.93	-1.03	-0.47
AGWRC[1]	0.999	-17.01	-16.52	62.05	-18.15	-14.21	-13.71	-21.58	-18.29
BASETP	-50	2.16	-1.35	27.55	0.85	4.07	3.47	0.28	2.01
BASETP	-10	0.39	-0.26	4.87	0.17	0.74	0.60	0.06	0.39
BASETP	10	-0.37	0.25	-4.61	-0.17	-0.72	-0.54	-0.06	-0.37
BASETP	50	-1.71	1.19	-20.52	-0.87	-3.35	-2.30	-0.30	-1.71
DEEPFR	-50	3.34	1.92	6.20	3.58	3.18	3.18	3.42	3.34
DEEPFR	-10	0.67	0.38	1.25	0.72	0.64	0.63	0.68	0.67
DEEPFR	10	-0.67	-0.38	-1.26	-0.72	-0.64	-0.63	-0.68	-0.67
DEEPFR	50	-3.33	-1.89	-6.35	-3.59	-3.18	-3.16	-3.42	-3.33
INFILT	-50	0.24	15.27	-30.71	-0.35	-2.73	2.93	1.50	0.24
INFILT	-10	-0.04	2.16	-4.63	0.00	-0.57	0.38	0.11	-0.04
INFILT	10	0.06	-1.88	4.10	0.00	0.56	-0.31	-0.08	0.06
INFILT	50	0.47	-7.54	16.62	-0.06	2.79	-1.18	-0.04	0.47
INTFW	-50	-0.33	0.44	0.87	-0.28	-0.71	-0.12	-0.17	-0.33
INTFW	-10	-0.04	-0.01	0.12	-0.04	-0.10	-0.02	-0.02	-0.04
INTFW	10	0.04	0.01	-0.10	0.03	0.08	0.02	0.02	0.04
INTFW	50	0.15	0.07	-0.42	0.11	0.31	0.08	0.08	0.15
LZSN	-50	5.51	8.29	-7.80	9.65	3.50	-6.51	13.99	5.51
LZSN	-10	0.78	1.07	-1.29	1.67	0.72	-1.57	2.04	0.78
LZSN	10	-0.73	-0.96	1.10	-1.56	-0.71	1.43	-1.83	-0.73
LZSN	50	-3.49	-4.13	3.04	-7.17	-3.37	5.15	-7.66	-3.49
CEPSC	-50	2.85	0.68	13.68	1.67	6.81	1.41	1.06	2.85
CEPSC	-10	0.48	0.14	2.13	0.33	1.19	0.24	0.07	0.48
CEPSC	10	-0.46	-0.14	-2.09	-0.34	-1.14	-0.27	-0.05	-0.46
CEPSC	50	-2.10	-0.65	-8.91	-1.32	-4.94	-1.13	-0.72	-2.10
LZETP	-50	18.24	20.73	23.09	7.55	4.95	39.70	22.90	18.24
LZETP	-10	3.61	3.70	6.11	1.31	0.96	8.71	4.01	3.61
LZETP	10	-3.63	-3.74	-6.13	-1.36	-1.08	-8.77	-3.86	-3.63
LZETP	50	-11.32	-11.25	-18.20	-5.35	-4.31	-24.12	-12.84	-11.32
KVARY	-50	-0.28	-3.42	22.15	0.72	-0.32	-0.77	-0.68	-0.33
KVARY	-10	-0.05	-0.62	3.74	0.12	-0.07	-0.11	-0.12	-0.05
KVARY	10	0.05	0.59	-3.59	-0.11	0.07	0.11	0.12	0.05
KVARY	50	0.23	2.72	-16.12	-0.49	0.35	0.50	0.51	0.23
UZSN	-50	9.90	16.14	-1.37	4.33	15.00	14.40	5.80	9.90
UZSN	-10	1.40	2.41	0.00	0.62	2.04	2.17	0.78	1.40
UZSN	10	-1.20	-2.15	-0.07	-0.53	-1.60	-2.00	-0.72	-1.20
UZSN	50	-4.92	-9.00	0.58	-1.93	-6.64	-7.94	-3.25	-4.92

[1]Actual parameter value used

Water Quality Parameter Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 1998 through 2000, and model parameters established for 2012 conditions. The three HSPF parameters impacting the model's water quality response (**Table B. 8**) were increased and decreased by amounts that were consistent with the range of values for the parameter. The First Order Decay (FSTDEC) was the parameter with the greatest influence on monthly geometric mean concentration (**Table B. 9**). The reason behind the more pronounced impact of change in decay rate on concentration of bacteria in the stream is that changes in decay rate impact bacteria from nonpoint as well as point sources and direct-nonpoint sources. On the other hand, changes in maximum fecal coliform accumulation on the land (MON-SQOLIM) and wash-off rate for fecal coliform on land surface (WSQOP) only impact the nonpoint portion of the bacteria. Graphical depictions of the results of this sensitivity analysis can be seen in **Figure B. 19 Figure B. 21**.

Table B. 8 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0 – 2.3E+12
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	1.0
FSTDEC	In-stream First Order Decay Rate	1/day	1.0

Table B. 9 Percent change in average monthly *E. coli* mean for the years 1998-2000.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2000											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	10.93	10.24	10.56	9.83	12.97	36.51	44.48	66.55	24.21	28.46	27.38	19.29
FSTDEC	-10	2.05	1.93	1.99	1.86	2.39	5.37	5.88	8.21	3.68	4.16	4.05	3.16
FSTDEC	10	-1.99	-1.88	-1.93	-1.81	-2.30	-4.77	-5.03	-6.91	-3.34	-3.73	-3.64	-2.93
FSTDEC	50	-9.35	-8.88	-9.10	-8.59	-10.70	-19.62	-19.54	-26.32	-14.25	-15.65	-15.32	-12.97
SQOLIM	-50	-3.33	-2.16	-5.14	-4.62	-1.67	-0.88	-1.36	-1.24	-2.16	-0.98	-1.65	-1.45
SQOLIM	-25	-1.64	-1.04	-2.52	-2.24	-0.74	-0.36	-0.55	-0.50	-1.02	-0.41	-0.72	-0.66
SQOLIM	25	1.59	0.99	2.43	2.16	0.63	0.27	0.41	0.38	0.96	0.30	0.59	0.57
SQOLIM	50	3.16	1.95	4.81	4.21	1.16	0.48	0.69	0.66	1.88	0.53	1.07	1.08
WSQOP	-50	5.64	3.20	6.68	7.32	1.77	0.38	0.44	0.29	2.47	0.58	1.05	1.44
WSQOP	-10	0.66	0.38	0.85	0.90	0.21	0.04	0.05	0.03	0.31	0.07	0.12	0.17
WSQOP	10	-0.54	-0.32	-0.72	-0.76	-0.18	-0.03	-0.04	-0.03	-0.26	-0.06	-0.10	-0.14
WSQOP	50	-2.02	-1.20	-2.80	-2.86	-0.67	-0.13	-0.17	-0.10	-1.00	-0.21	-0.37	-0.53

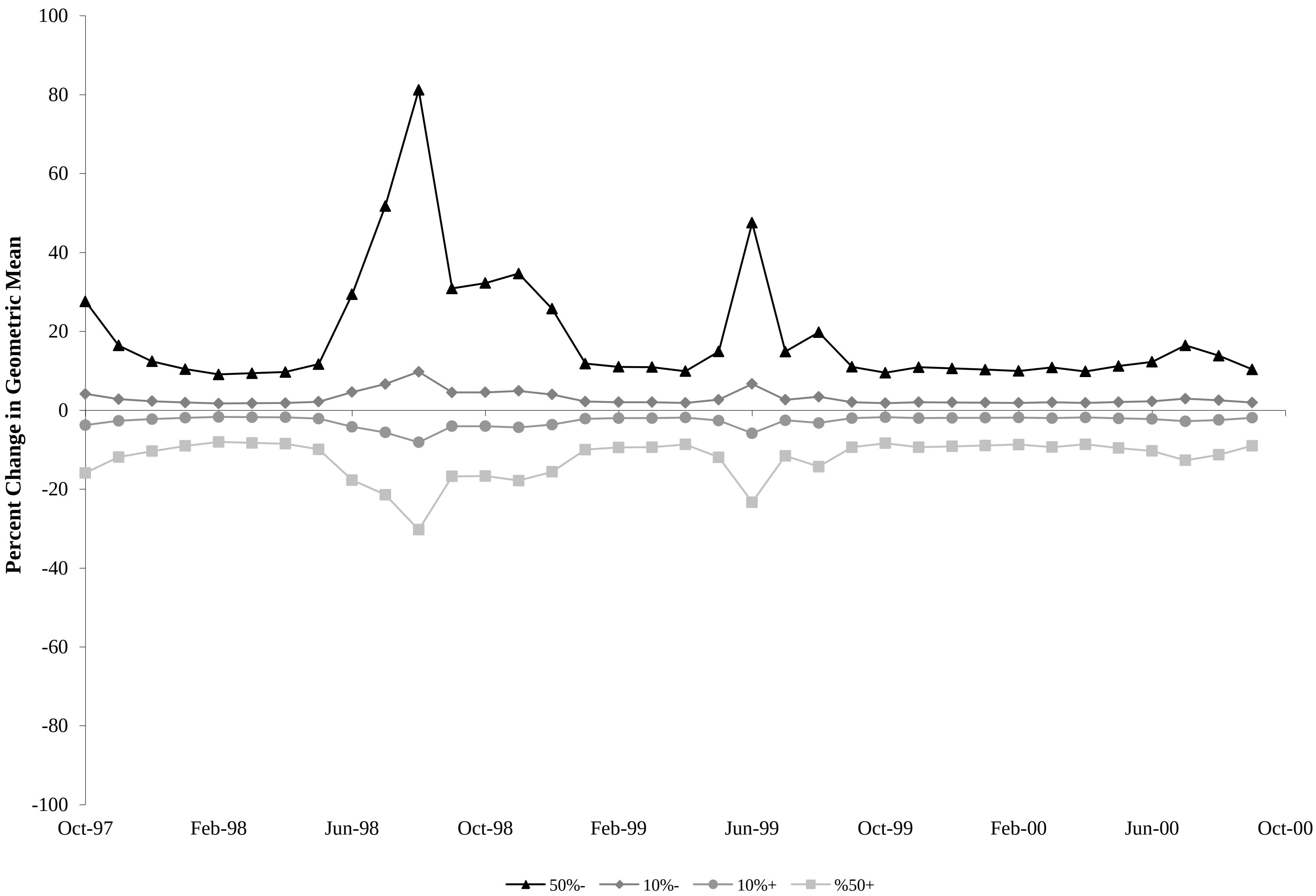

Figure B. 19 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the in-stream first-order decay rate (FSTDEC).

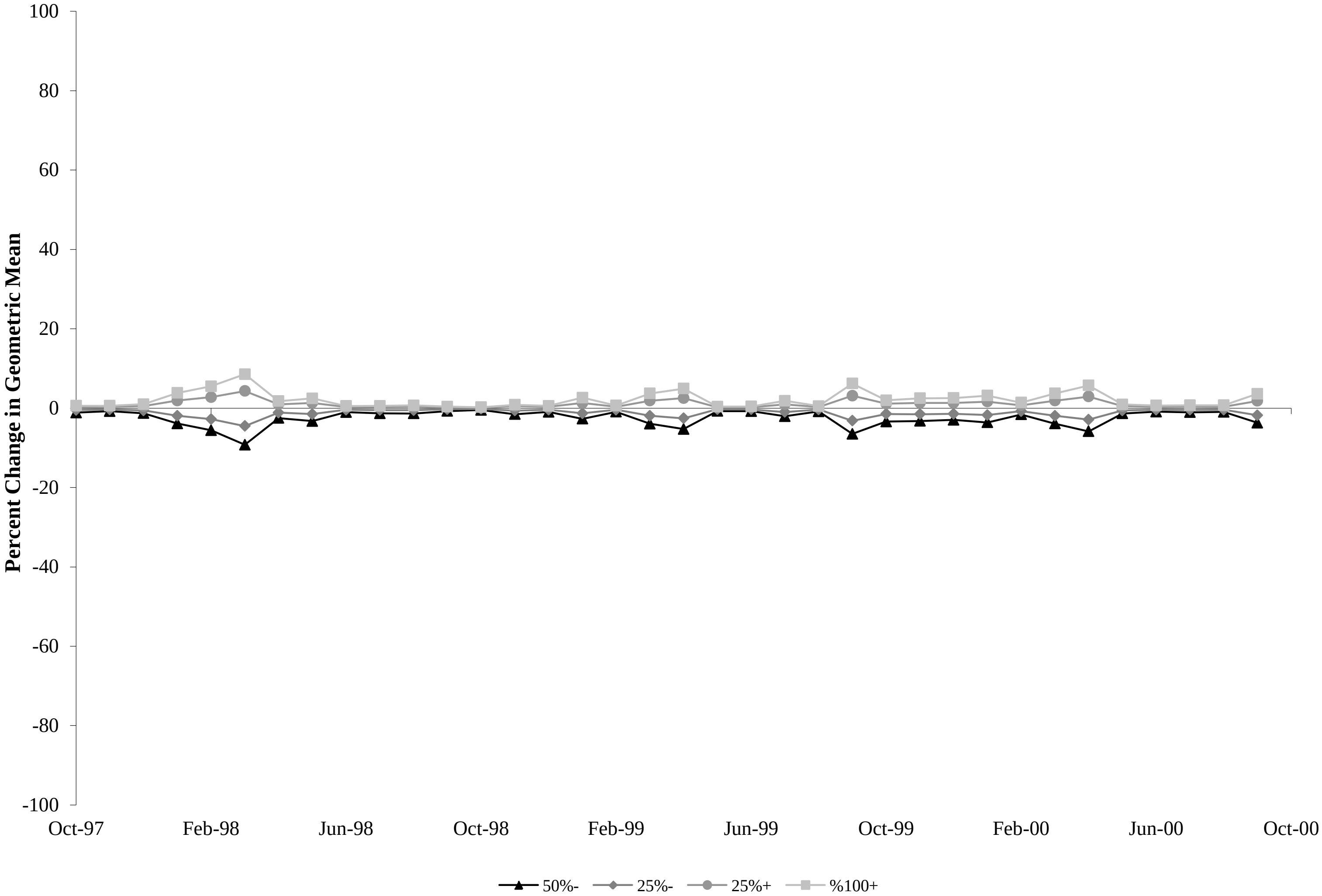

Figure B. 20 Results of sensitivity analysis on monthly mean concentrations as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

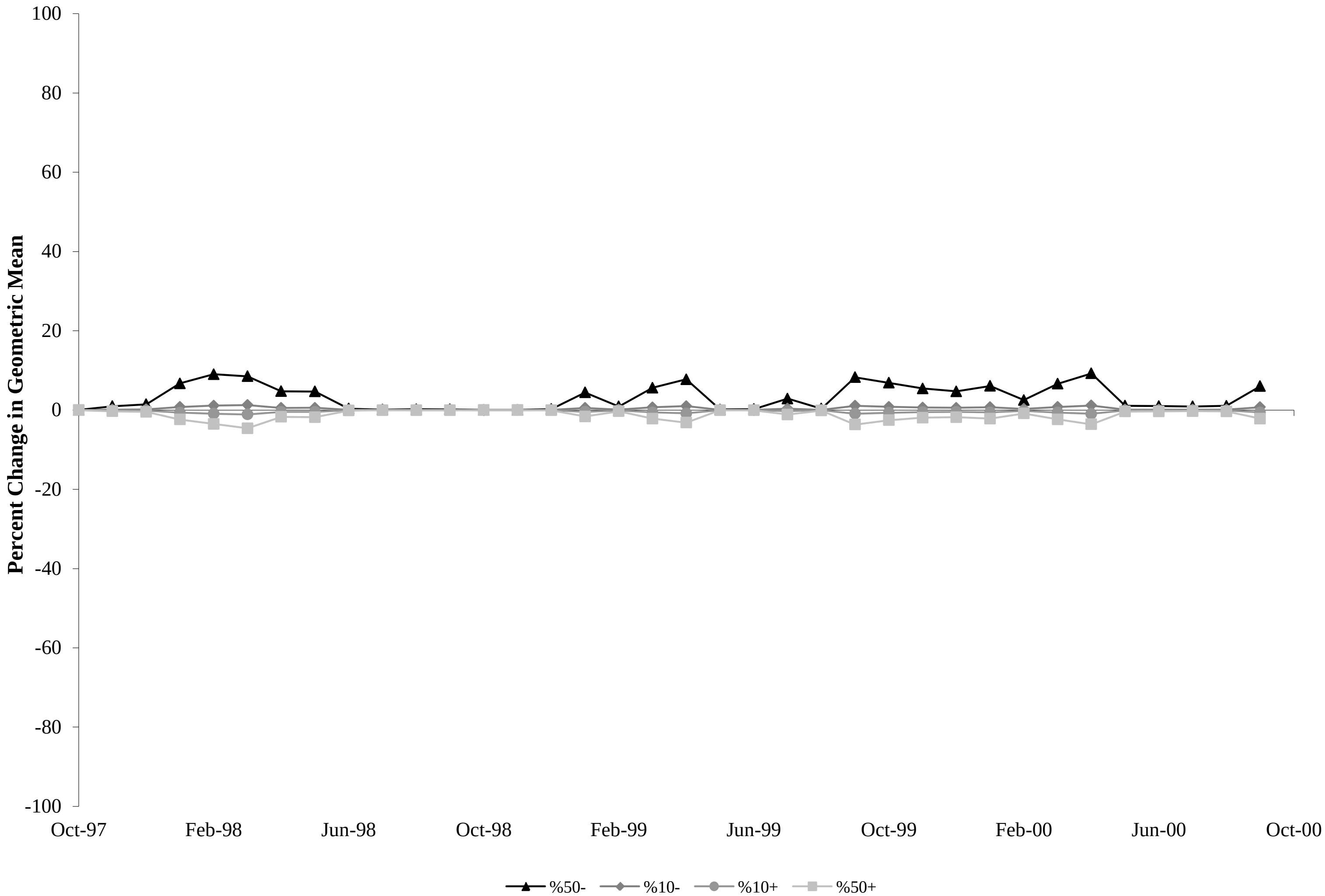

Figure B. 21 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the wash-off rate from land surfaces (WSQOP).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. It is evident in **Figure B. 22** that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs between land applied and direct loadings; a 100% increase in the land applied loads results in an increase of about 65% in stream loads, while a 100% increase in direct loads results in approximately a 25% increase in stream loads. Both direct loads and land applied loads have a significant impact on the geometric mean concentrations (**Figure B. 23** and **Figure B. 24**).

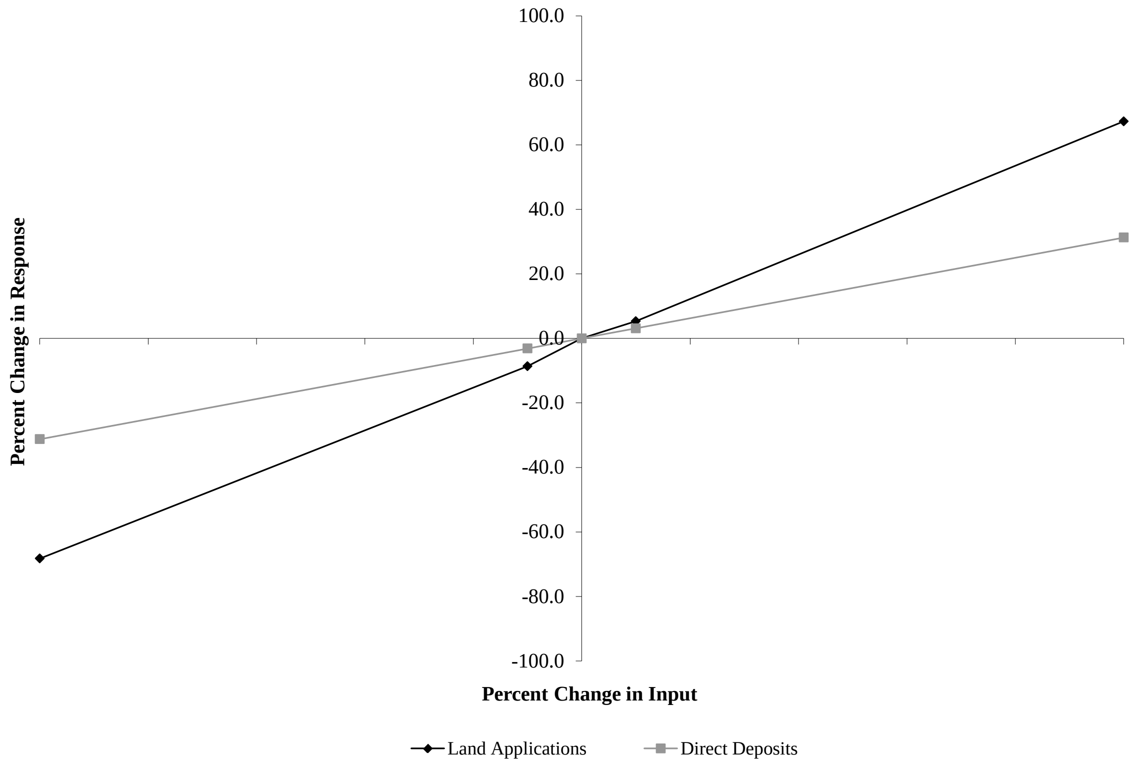

Figure B. 22 Results of total loading sensitivity analysis for outlet of the study area.

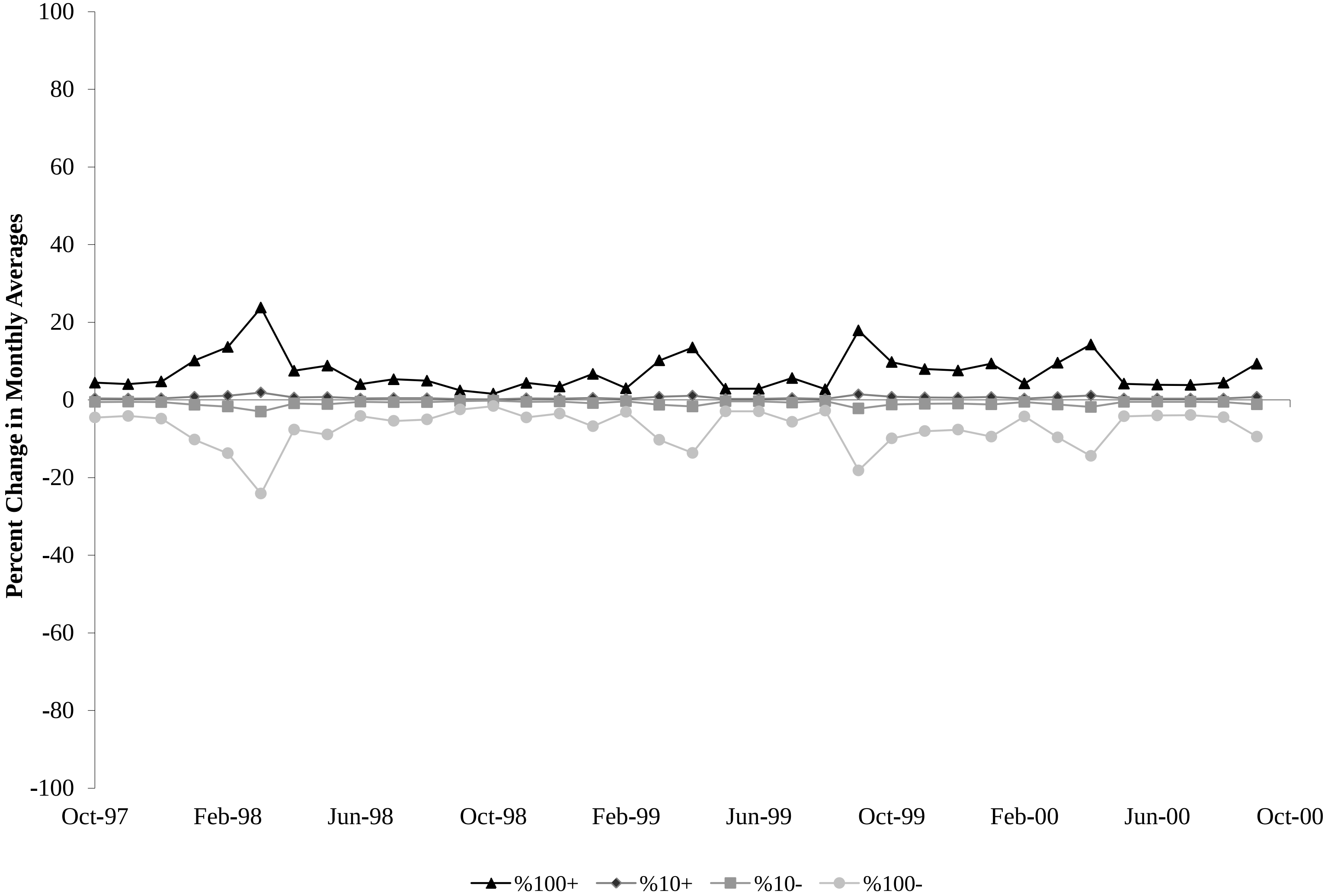

Figure B. 23 Results of sensitivity analysis on monthly geometric-mean concentrations in the study area, as affected by changes in land-based loadings.

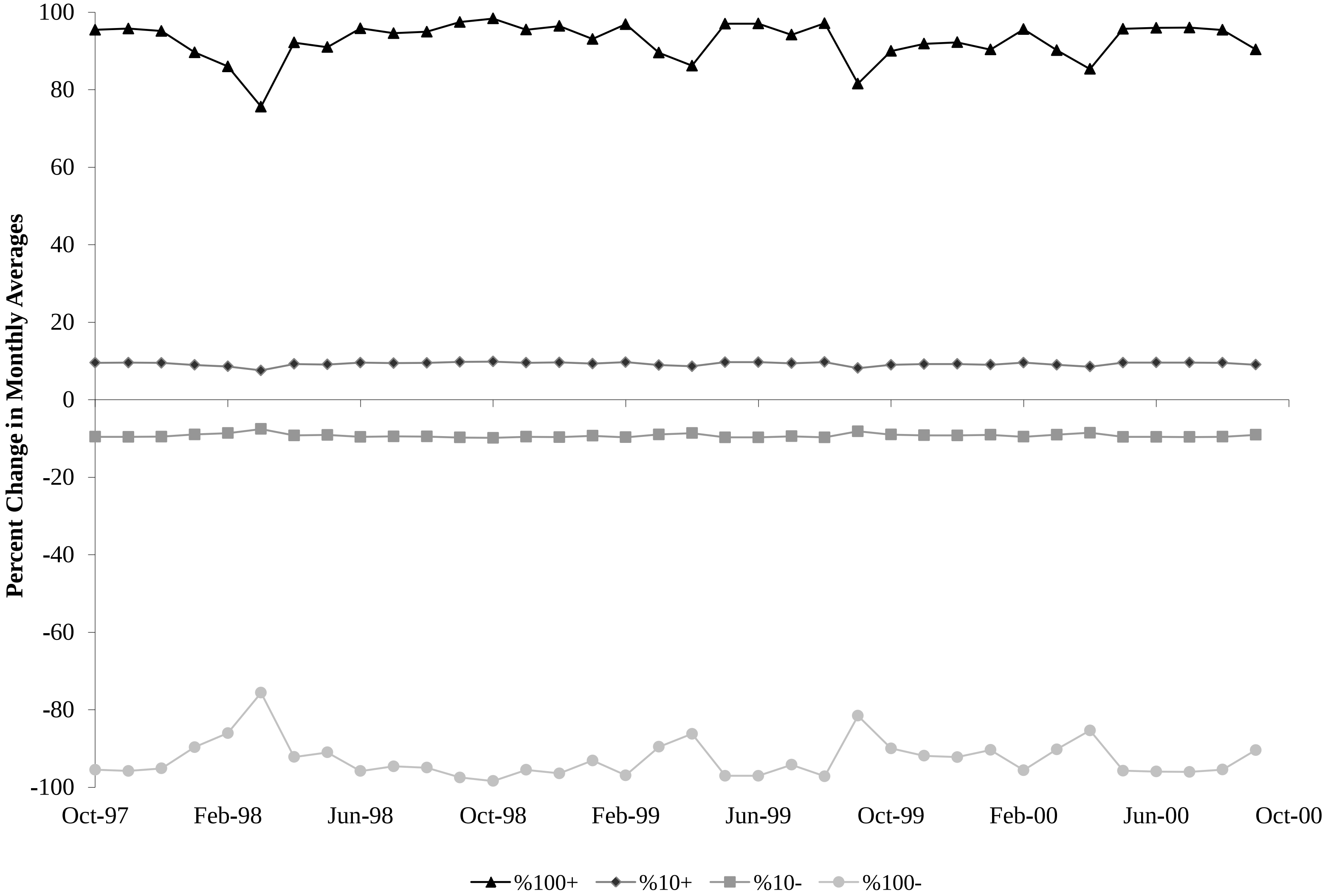

Figure B. 24 Results of sensitivity analysis on monthly geometric-mean concentrations in the study area, as affected by changes in loadings from direct nonpoint sources.

Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters are adjusted within appropriate ranges until the model performance is deemed acceptable. Water quality calibration involves comparing historical DEQ monitored data collected within the study area to simulated water quality concentrations obtained by running the computer model. The computer model used in the analysis is capable of generating a simulated output at any needed location within the watershed by placing a subwatershed outlet at that location within the model. This ability allows for the calibration process to honor spatial variability within the larger study area.

HSPF - Hydrologic Calibration and Validation

Paired-watershed approach was utilized in calibrating hydrologic parameters within the study area. Initial parameters were estimated from available spatial data and then adjusted based on rate of change in these parameters that was estimated from the nearby, hydrologically calibrated Chickahominy River watershed.

HSPF – Bacteria Water Quality Calibration

Water quality calibration is complicated by a number of factors; first, water quality (*E. coli*) concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of *E. coli* is particularly variable. Variability in location and timing of fecal deposition, variability in the density of bacteria in feces (among species and for an individual animal), environmental impacts on re-growth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling *E. coli* concentrations. Additionally, the VADEQ data were censored at specific high and low values. Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), and the rate of surface runoff that will remove 90% of stored fecal bacteria per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established. Observed *E. coli* monitored data were used in the calibration process. **Table B. 10** shows the model parameters utilized in calibration with their typical ranges, initial estimates, and final calibrated values. Bacteria calibration was conducted for the period of October 2002 to September 2007.

Table B. 10 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range	Initial Parameter Estimate	Calibrated Parameter Value
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 1.1E+11	0.0 – 2.3E+12
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.80	0.0 – 2.8
FSTDEC	1/day	0.01 – 10.00	1.0	0.01 - 10.0

Figure B. 25 through **Figure B. 31** show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the modeled values are daily averages based on hourly modeling. The hourly bacteria concentrations as predicted by the model have a rage wider than the average daily and encompass the high and low observed data points. The modeled data follows the trend of monitored data.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. **Table B. 11** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the simulated and observed results at the calibration locations.

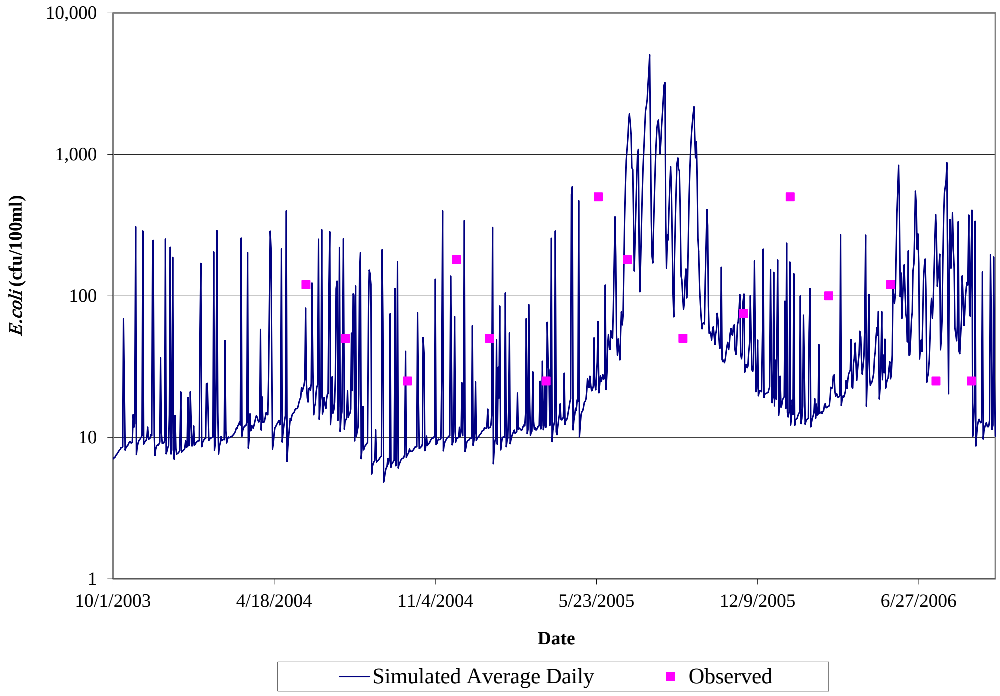

Figure B. 25 ***E. coli*** **calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CCH000.54 in subwatershed 38 on Crewes Channel.**

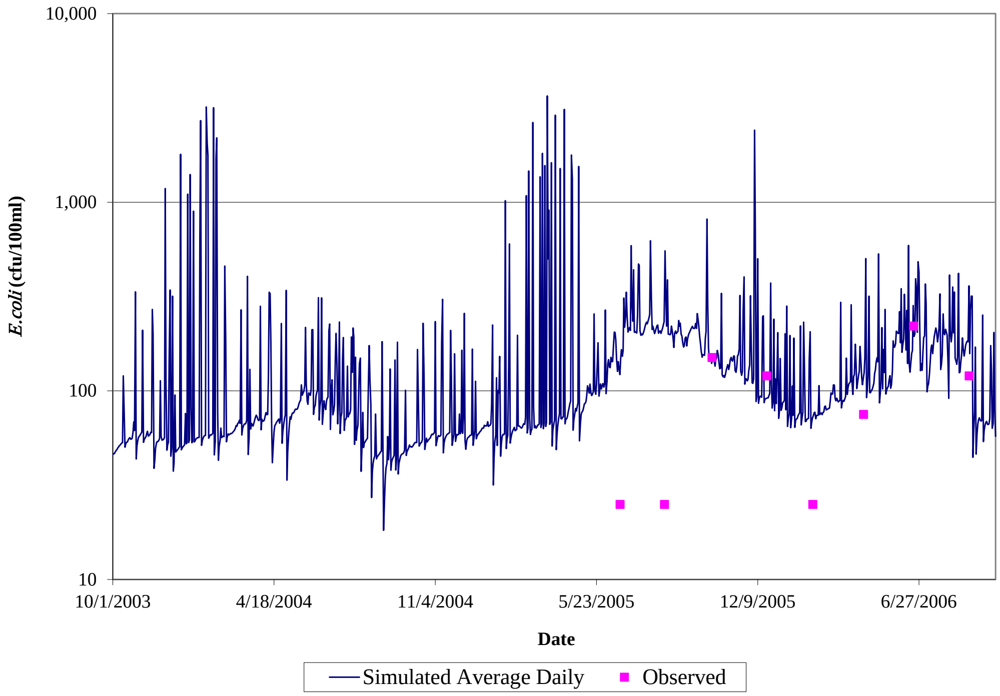

Figure B. 26 ***E. coli*** **calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-TIC002.69 in subwatershed 39 on Turkey Island Creek.**

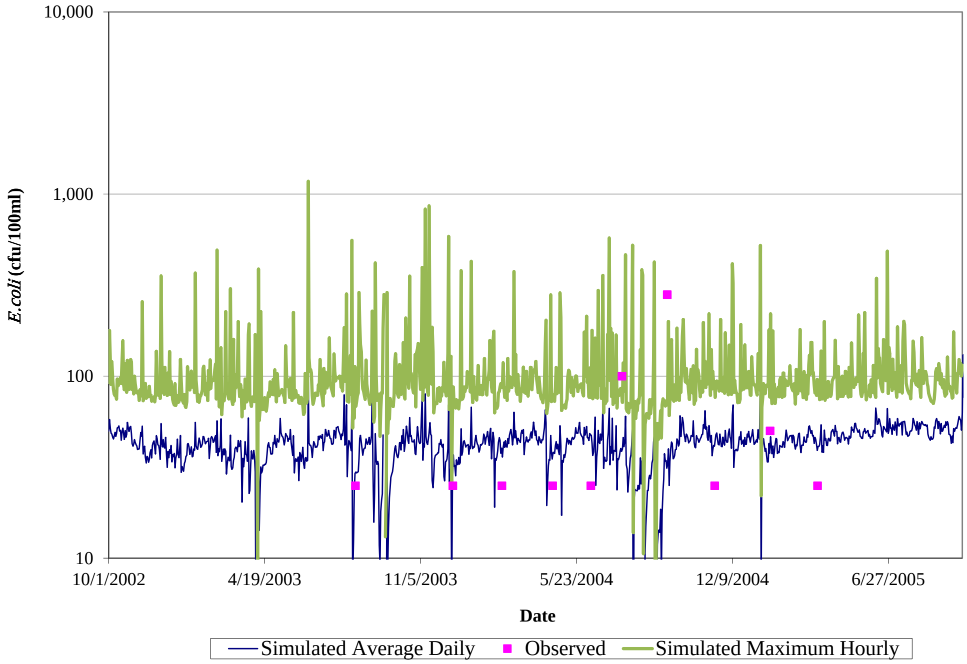

Figure B. 27 ***E. coli*** **calibration for 10/1/2002 to 9/30/2005 for VADEQ station 2-UCK001.23 in subwatershed 8 on Upper Chippokes Creek.**

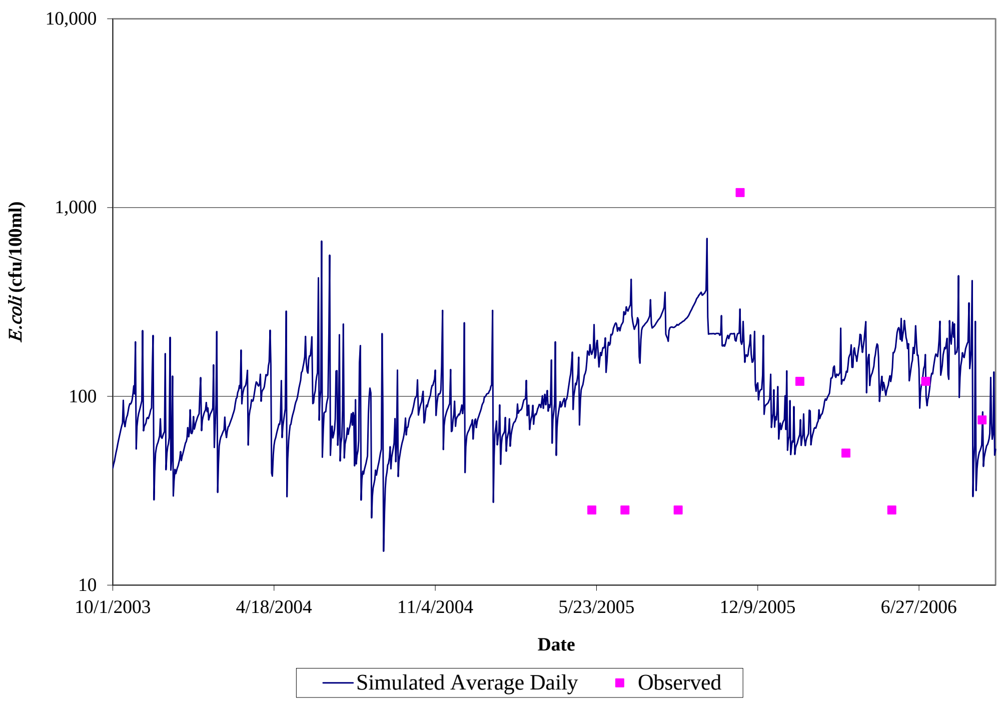

Figure B. 28 ***E. coli*** **calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-UCK007.73 in subwatershed 11 on Upper Chippokes Creek.**

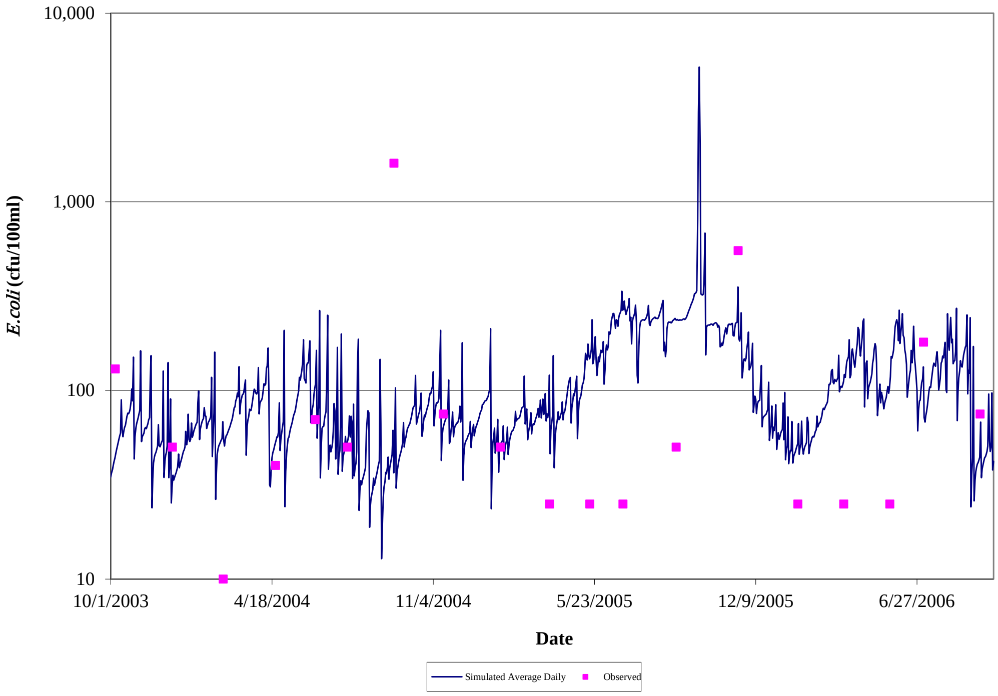

Figure B. 29 ***E. coli*** **calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-WRD005.40 in subwatershed 18 on Wards Creek.**

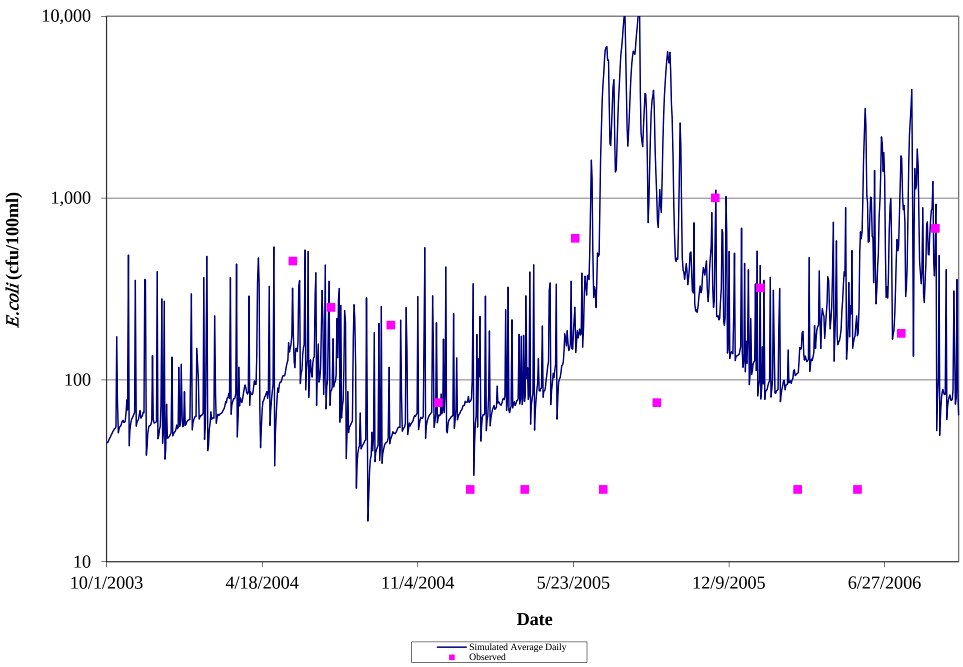

Figure B. 30 ***E. coli*** **calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-WSN000.85 in subwatershed 41 on Western Run.**

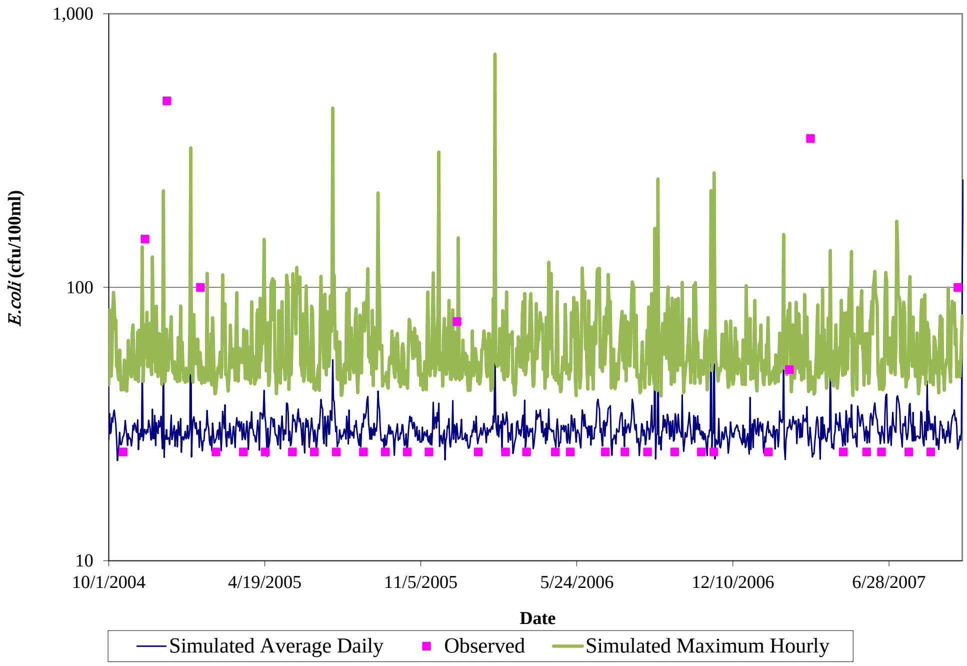

Figure B. 31 ***E. coli*** **calibration for 10/1/2004 to 9/30/2007 for VADEQ station 2-JMS055.94 in subwatershed 3 on the James River.**

Table B. 11 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the calibration period.

Station	Subwatershed	Maximum Value (cfu/100 mL)		Geometric Mean (cfu/100 mL)		SS % violations [1]	
		Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
2-CCH000.54	38	500	5,060	81.04	32.39	13.33	11.04
2-TIC002.69	39	220	3,663	69.70	107.35	0.00	10.22
2- UCK001.23	8	280	105	39.19	41.00	10.00	0.00
2-UCK007.73	11	1,200	686	66.46	107.53	11.11	10.31
2-WRD005.40	18	1,600	5,173	59.35	91.60	10.53	9.40
2-WSN000.85	41	1,000	11,190	125.18	179.06	40.00	32.94
2-JMS055.94	3	481	120	40.07	30.16	5.71	0.00

[1] SS = single sample instantaneous standard violations (>235 cfu/100 mL)

HSPF – Bacteria Water Quality Validation

Bacteria water quality model validation was performed for the period of October 2006 to September 2010. **Figure B. 32** through **Figure B. 34** show the results of water quality validation. **Table B. 12** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations.

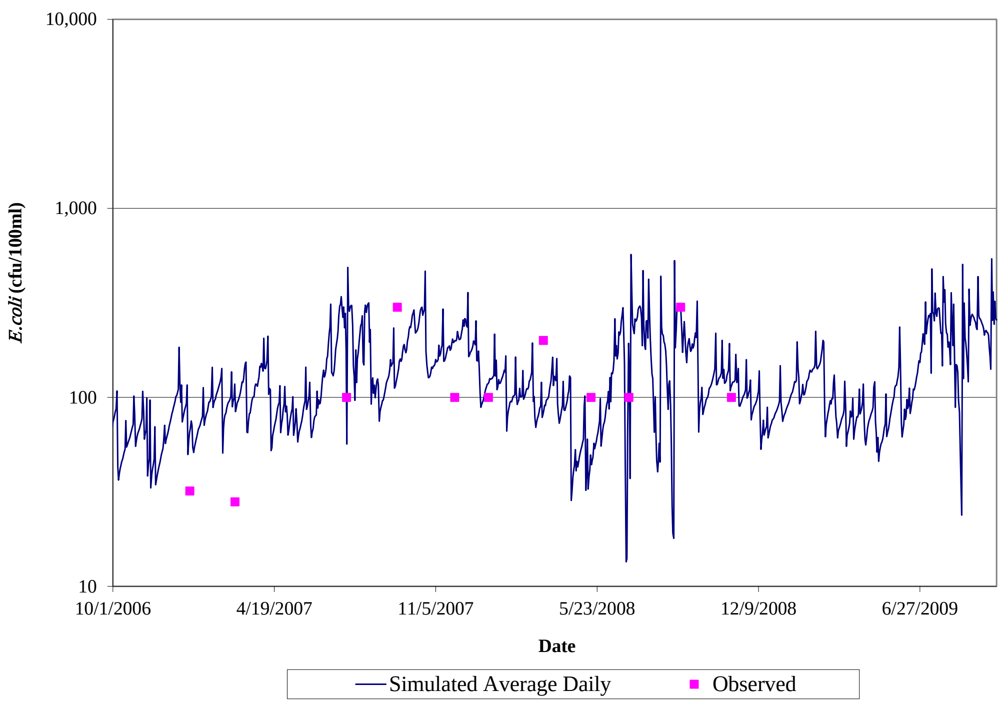

Figure B. 32 ***E. coli*** **validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-WER001.93 in subwatershed 33 on West Run.**

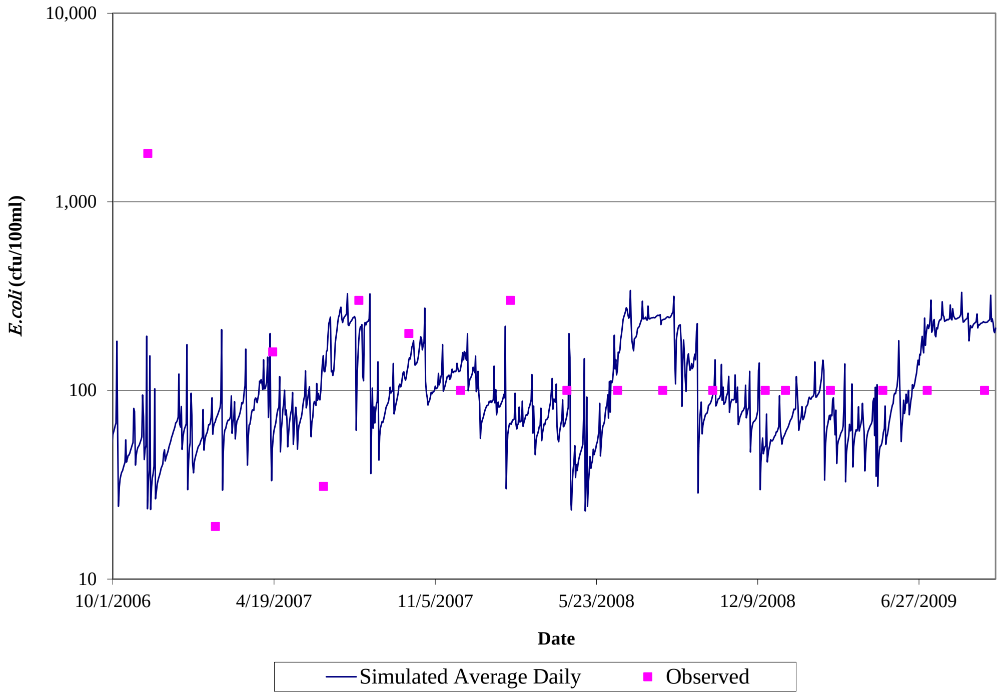

Figure B. 33 ***E. coli*** **validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-WRD005.40 in subwatershed 18 on Wards Creek.**

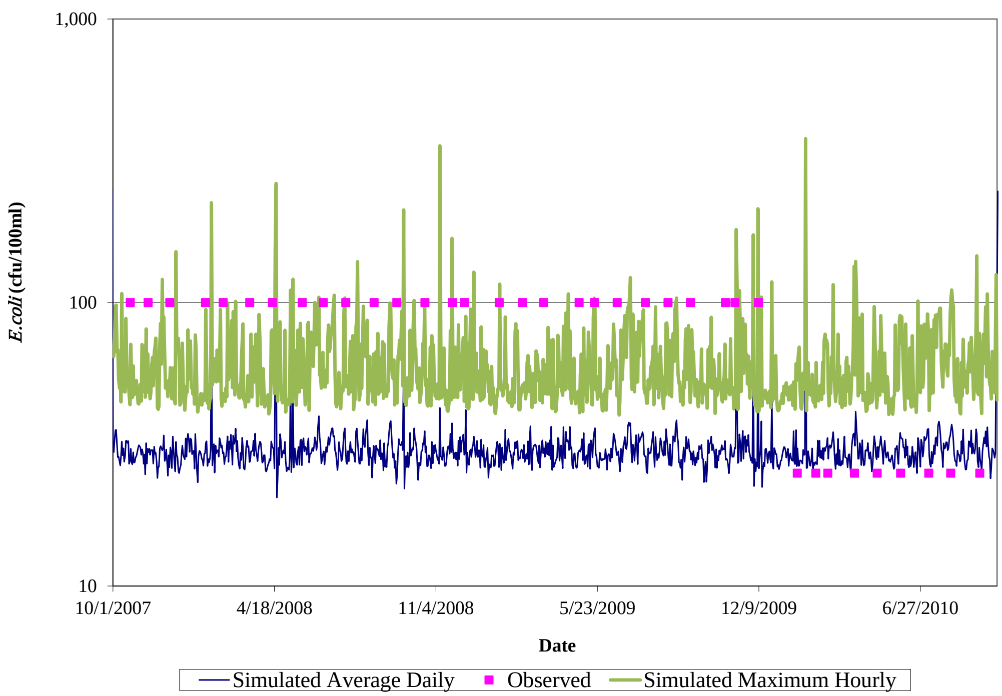

Figure B. 34 ***E. coli*** **validation for 10/1/2007 to 9/30/2010 for VADEQ station 2-JMS055.94 in subwatershed 3 on the James River.**

Table B. 12 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period.

Station	Subwatershed	Maximum Value (cfu/100 mL)		Geometric Mean (cfu/100 mL)		SS % violations [1]	
		Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
2-WER001.93	33	300	570	77.69	115.20	16.67	12.14
2-WRD005.40	18	1,800	339	120.92	95.00	16.67	10.04
2-JMS055.94	3	100	134	70.71	29.90	0.00	0.00

[1] SS = single sample instantaneous standard violations (>235 cfu/100 mL)

APPENDIX C

Current conditions fecal coliform loads

Table C. 1 Current conditions of land applied fecal coliform load of Turkey Island Creek (NTU 93.1):

Land-use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
LMIR	18.9E11	17.0E11	18.5E11	17.8E11	18.3E11	17.6E11	17.9E11	17.9E11	17.3E11	17.8E11	17.3E11	18.4E11	21.5E12
Forest	26.6E12	24.0E12	26.6E12	25.7E12	26.6E12	25.7E12	26.6E12	26.6E12	25.7E12	26.6E12	25.7E12	26.6E12	31.3E13
Pasture	10.5E12	94.8E11	10.5E12	10.1E12	10.4E12	10.1E12	10.4E12	10.4E12	10.1E12	10.5E12	10.1E12	10.5E12	12.3E13
Commercial	62.2E07	56.2E07	62.2E07	60.2E07	62.2E07	60.2E07	62.2E07	62.2E07	60.2E07	62.2E07	60.2E07	62.2E07	73.2E08
LAX	79.3E09	71.7E09	10.7E10	13.7E10	14.1E10	16.3E10	16.9E10	16.9E10	13.7E10	10.7E10	10.3E10	79.3E09	14.6E11
OpenSpace	52.7E09	47.6E09	52.7E09	51.0E09	52.7E09	51.0E09	52.7E09	52.7E09	51.0E09	52.7E09	51.0E09	52.7E09	62.1E10
Crop	35.2E11	31.8E11	35.2E11	34.1E11	35.2E11	34.1E11	35.2E11	35.2E11	34.1E11	35.2E11	34.1E11	35.2E11	41.4E12
Wetland	42.4E11	38.3E11	42.4E11	41.0E11	42.4E11	41.0E11	42.4E11	42.4E11	41.0E11	42.4E11	41.0E11	42.4E11	49.9E12
Barren	17.8E10	16.1E10	17.8E10	17.2E10	17.8E10	17.2E10	17.8E10	17.8E10	17.2E10	17.8E10	17.2E10	17.8E10	21.0E11

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of Turkey Island Creek (NTU 93.1):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Loads (cfu/yr)
Human/Pet	36	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	36	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	36	43.2E08	39.0E08	43.2E08	41.8E08	43.2E08	41.8E08	43.2E08	43.2E08	41.8E08	43.2E08	41.8E08	43.2E08	50.9E09
Human/Pet	37	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	37	71.0E08	64.2E08	94.7E08	13.8E09	14.2E09	16.0E09	16.6E09	16.6E09	13.8E09	94.7E08	91.7E08	71.0E08	14.0E10
Wildlife	37	12.0E09	10.9E09	12.0E09	11.6E09	12.0E09	11.6E09	12.0E09	12.0E09	11.6E09	12.0E09	11.6E09	12.0E09	14.1E10
Human/Pet	38	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	38	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	38	25.5E09	23.0E09	25.5E09	24.7E09	25.5E09	24.7E09	25.5E09	25.5E09	24.7E09	25.5E09	24.7E09	25.5E09	30.0E10
Human/Pet	39	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	39	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	39	80.3E09	72.5E09	80.3E09	77.7E09	80.3E09	77.7E09	80.3E09	80.3E09	77.7E09	80.3E09	77.7E09	80.3E09	94.5E10
Human/Pet	40	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	40	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	40	69.5E08	62.8E08	69.5E08	67.3E08	69.5E08	67.3E08	69.5E08	69.5E08	67.3E08	69.5E08	67.3E08	69.5E08	81.9E09
Human/Pet	41	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	41	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	41	21.5E09	19.4E09	21.5E09	20.8E09	21.5E09	20.8E09	21.5E09	21.5E09	20.8E09	21.5E09	20.8E09	21.5E09	25.3E10
Human/Pet	42	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	42	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	42	48.5E09	43.8E09	48.5E09	46.9E09	48.5E09	46.9E09	48.5E09	48.5E09	46.9E09	48.5E09	46.9E09	48.5E09	57.1E10

Table C. 3 Existing annual (2012) loads from land-based sources of Turkey Island Creek (NTU 93.1):

Source	LMIR	Pasture	Commercial	LAX	Open Space	Crop	Wetland	Barren	Water	Forest
Beaver	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	65.7E08	00E00
Beef	00E00	21.5E12	00E00	10.2E11	00E00	00E00	00E00	00E00	11.3E10	00E00
Beef calves	00E00	50.0E11	00E00	23.7E10	00E00	00E00	00E00	00E00	26.3E09	00E00
cats	15.7E06	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Deer	60.4E08	75.0E11	00E00	32.5E09	17.1E09	41.8E11	35.2E11	00E00	00E00	28.0E12
dogs	18.4E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Duck	18.4E05	16.3E07	00E00	91.5E05	55.1E05	16.4E07	36.0E08	36.9E05	00E00	33.1E08
Goose	19.6E07	17.4E09	00E00	97.4E07	58.7E07	17.4E09	38.4E10	39.3E07	00E00	35.2E10
Hog	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Horse	00E00	29.4E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Muskrat	63.3E08	56.2E10	00E00	31.5E09	19.0E09	56.4E10	12.4E12	12.7E09	00E00	11.4E12
People On Failing Septics	27.7E11	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
People on Straight Pipes	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	21.5E11	00E00
Raccoon	26.0E10	58.8E12	73.2E08	13.9E10	58.4E10	36.7E12	33.6E12	20.9E11	00E00	27.4E13
Sheep	00E00	27.3E10	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Turkey	00E00	88.5E07	00E00	38.3E05	00E00	49.3E07	16.6E08	00E00	00E00	13.2E09

Table C. 4 Existing annual loads from direct-deposition sources of Turkey Island Creek (NTU 93.1):

Source	Annual Total Loads (cfu/yr)
Beaver	15.5E09
Beef	11.3E10
Beef calves	26.3E09
Deer	10.8E10
Duck	28.4E07
Goose	19.9E09
Hog	00E00
Horse	00E00
Muskrat	11.8E11
People on Straight Pipes	64.6E11
Raccoon	10.2E11
Sheep	00E00
Turkey	40.7E06

Table C. 5 Current conditions of land applied fecal coliform load of Westover to Chippokes Pt. (NTU 91.1):

Land-use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Open Space	47.1E10	42.5E10	47.1E10	45.5E10	47.1E10	45.5E10	47.1E10	47.1E10	45.5E10	47.1E10	45.5E10	47.1E10	55.4E11
Crop	19.1E12	17.5E12	28.4E12	27.8E12	28.4E12	17.6E12	18.2E12	18.2E12	20.6E12	28.4E12	27.8E12	19.1E12	27.1E13
Barren	28.2E11	25.5E11	28.2E11	27.3E11	28.2E11	27.3E11	28.2E11	28.2E11	27.3E11	28.2E11	27.3E11	28.2E11	33.2E12
Forest	11.4E13	10.3E13	11.4E13	11.0E13	11.4E13	11.0E13	11.4E13	11.4E13	11.0E13	11.4E13	11.0E13	11.4E13	13.4E14
Commercial	12.8E08	11.6E08	12.8E08	12.4E08	12.8E08	12.4E08	12.8E08	12.8E08	12.4E08	12.8E08	12.4E08	12.8E08	15.1E09
LAX	64.6E10	58.3E10	81.4E10	99.6E10	10.3E11	11.6E11	12.0E11	12.0E11	99.6E10	81.4E10	78.8E10	64.6E10	10.9E12
LMIR	88.1E11	79.0E11	86.2E11	82.9E11	85.0E11	81.6E11	83.1E11	83.1E11	80.4E11	82.5E11	80.4E11	85.6E11	99.8E12
Pasture	56.9E12	51.4E12	56.6E12	54.5E12	56.4E12	55.4E12	57.2E12	57.2E12	54.5E12	56.6E12	54.8E12	56.9E12	66.8E13

Table C. 6 Monthly, directly deposited fecal coliform loads in each reach of Westover to Chippokes Pt. (NTU 91.1):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	2	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	2	47.6E08	43.0E08	63.5E08	92.2E08	95.2E08	10.8E09	11.1E09	11.1E09	92.2E08	63.5E08	61.4E08	47.6E08	93.6E09
Wildlife	2	17.4E10	15.7E10	17.4E10	16.8E10	17.4E10	16.8E10	17.4E10	17.4E10	16.8E10	17.4E10	16.8E10	17.4E10	20.4E11
Human/Pet	3	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	3	10.5E08	94.8E07	14.0E08	20.3E08	21.0E08	23.7E08	24.5E08	24.5E08	20.3E08	14.0E08	13.5E08	10.5E08	20.6E09
Wildlife	3	34.0E10	30.7E10	34.0E10	32.9E10	34.0E10	32.9E10	34.0E10	34.0E10	32.9E10	34.0E10	32.9E10	34.0E10	40.1E11
Human/Pet	4	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	4	54.0E08	48.8E08	72.0E08	10.5E09	10.8E09	12.2E09	12.6E09	12.6E09	10.5E09	72.0E08	69.7E08	54.0E08	10.6E10
Wildlife	4	24.7E10	22.3E10	24.7E10	23.9E10	24.7E10	23.9E10	24.7E10	24.7E10	23.9E10	24.7E10	23.9E10	24.7E10	29.0E11
Human/Pet	5	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	5	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Wildlife	5	42.6E09	38.5E09	42.6E09	41.2E09	42.6E09	41.2E09	42.6E09	42.6E09	41.2E09	42.6E09	41.2E09	42.6E09	50.1E10
Human/Pet	6	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	6	24.7E08	22.3E08	32.9E08	47.8E08	49.4E08	55.8E08	57.6E08	57.6E08	47.8E08	32.9E08	31.9E08	24.7E08	48.6E09
Wildlife	6	21.6E10	19.6E10	21.6E10	20.9E10	21.6E10	20.9E10	21.6E10	21.6E10	20.9E10	21.6E10	20.9E10	21.6E10	25.5E11
Human/Pet	7	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	7	10.5E08	94.8E07	14.0E08	20.3E08	21.0E08	23.7E08	24.5E08	24.5E08	20.3E08	14.0E08	13.5E08	10.5E08	20.6E09
Wildlife	7	32.5E10	29.3E10	32.5E10	31.4E10	32.5E10	31.4E10	32.5E10	32.5E10	31.4E10	32.5E10	31.4E10	32.5E10	38.2E11
Human/Pet	14	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	14	72.9E07	65.9E07	97.2E07	14.1E08	14.6E08	16.5E08	17.0E08	17.0E08	14.1E08	97.2E07	94.1E07	72.9E07	14.3E09
Wildlife	14	73.2E09	66.1E09	73.2E09	70.8E09	73.2E09	70.8E09	73.2E09	73.2E09	70.8E09	73.2E09	70.8E09	73.2E09	86.2E10

Table C. 7 Monthly, directly deposited fecal coliform loads in each reach of Westover to Chippokes Pt. (NTU 91.1):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	15	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	15	13.2E08	11.9E08	17.6E08	25.5E08	26.3E08	29.7E08	30.7E08	30.7E08	25.5E08	17.6E08	17.0E08	13.2E08	25.9E09
Wildlife	15	66.8E09	60.3E09	66.8E09	64.7E09	66.8E09	64.7E09	66.8E09	66.8E09	64.7E09	66.8E09	64.7E09	66.8E09	78.7E10
Human/Pet	16	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	16	35.7E08	32.3E08	47.6E08	69.1E08	71.4E08	80.6E08	83.3E08	83.3E08	69.1E08	47.6E08	46.1E08	35.7E08	70.2E09
Wildlife	16	13.0E10	11.7E10	13.0E10	12.5E10	13.0E10	12.5E10	13.0E10	13.0E10	12.5E10	13.0E10	12.5E10	13.0E10	15.3E11
Human/Pet	17	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	17	17.4E08	15.7E08	23.2E08	33.7E08	34.8E08	39.3E08	40.6E08	40.6E08	33.7E08	23.2E08	22.5E08	17.4E08	34.2E09
Wildlife	17	25.2E09	22.7E09	25.2E09	24.4E09	25.2E09	24.4E09	25.2E09	25.2E09	24.4E09	25.2E09	24.4E09	25.2E09	29.6E10
Human/Pet	18	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	18	10.9E09	98.8E08	14.6E09	21.2E09	21.9E09	24.7E09	25.5E09	25.5E09	21.2E09	14.6E09	14.1E09	10.9E09	21.5E10
Wildlife	18	12.4E10	11.2E10	12.4E10	12.0E10	12.4E10	12.0E10	12.4E10	12.4E10	12.0E10	12.4E10	12.0E10	12.4E10	14.6E11
Human/Pet	19	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	19	14.2E08	12.8E08	18.9E08	27.5E08	28.4E08	32.1E08	33.2E08	33.2E08	27.5E08	18.9E08	18.3E08	14.2E08	27.9E09
Wildlife	19	51.0E09	46.0E09	51.0E09	49.3E09	51.0E09	49.3E09	51.0E09	51.0E09	49.3E09	51.0E09	49.3E09	51.0E09	60.0E10
Human/Pet	20	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	20	18.3E08	16.5E08	24.4E08	35.4E08	36.6E08	41.3E08	42.7E08	42.7E08	35.4E08	24.4E08	23.6E08	18.3E08	36.0E09
Wildlife	20	32.7E09	29.6E09	32.7E09	31.7E09	32.7E09	31.7E09	32.7E09	32.7E09	31.7E09	32.7E09	31.7E09	32.7E09	38.6E10
Human/Pet	21	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	21	40.9E07	37.0E07	54.6E07	79.2E07	81.9E07	92.4E07	95.5E07	95.5E07	79.2E07	54.6E07	52.8E07	40.9E07	80.4E08
Wildlife	21	45.3E09	40.9E09	45.3E09	43.8E09	45.3E09	43.8E09	45.3E09	45.3E09	43.8E09	45.3E09	43.8E09	45.3E09	53.3E10

Table C. 8 Monthly, directly deposited fecal coliform loads in each reach of Westover to Chippokes Pt. (NTU 91.1):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	22	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	22	40.9E07	37.0E07	54.6E07	79.2E07	81.9E07	92.4E07	95.5E07	95.5E07	79.2E07	54.6E07	52.8E07	40.9E07	80.4E08
Wildlife	22	12.6E09	11.4E09	12.6E09	12.2E09	12.6E09	12.2E09	12.6E09	12.6E09	12.2E09	12.6E09	12.2E09	12.6E09	14.9E10
Human/Pet	23	91.4E09	82.6E09	91.4E09	88.5E09	91.4E09	88.5E09	91.4E09	91.4E09	88.5E09	91.4E09	88.5E09	91.4E09	10.8E11
Livestock	23	13.2E08	11.9E08	17.6E08	25.5E08	26.3E08	29.7E08	30.7E08	30.7E08	25.5E08	17.6E08	17.0E08	13.2E08	25.9E09
Wildlife	23	30.1E09	27.2E09	30.1E09	29.1E09	30.1E09	29.1E09	30.1E09	30.1E09	29.1E09	30.1E09	29.1E09	30.1E09	35.4E10
Human/Pet	24	45.7E10	41.3E10	45.7E10	44.2E10	45.7E10	44.2E10	45.7E10	45.7E10	44.2E10	45.7E10	44.2E10	45.7E10	53.8E11
Livestock	24	12.3E08	11.1E08	16.4E08	23.8E08	24.6E08	27.7E08	28.6E08	28.6E08	23.8E08	16.4E08	15.8E08	12.3E08	24.1E09
Wildlife	24	27.9E09	25.2E09	27.9E09	27.0E09	27.9E09	27.0E09	27.9E09	27.9E09	27.0E09	27.9E09	27.0E09	27.9E09	32.9E10
Human/Pet	25	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	25	16.4E08	14.8E08	21.8E08	31.7E08	32.7E08	37.0E08	38.2E08	38.2E08	31.7E08	21.8E08	21.1E08	16.4E08	32.2E09
Wildlife	25	28.2E09	25.5E09	28.2E09	27.3E09	28.2E09	27.3E09	28.2E09	28.2E09	27.3E09	28.2E09	27.3E09	28.2E09	33.2E10
Human/Pet	26	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	26	32.0E07	28.9E07	42.7E07	61.9E07	64.0E07	72.2E07	74.6E07	74.6E07	61.9E07	42.7E07	41.3E07	32.0E07	62.9E08
Wildlife	26	29.8E09	27.0E09	29.8E09	28.9E09	29.8E09	28.9E09	29.8E09	29.8E09	28.9E09	29.8E09	28.9E09	29.8E09	35.1E10
Human/Pet	27	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	27	12.3E08	11.1E08	16.4E08	23.8E08	24.6E08	27.7E08	28.6E08	28.6E08	23.8E08	16.4E08	15.8E08	12.3E08	24.1E09
Wildlife	27	17.3E09	15.6E09	17.3E09	16.7E09	17.3E09	16.7E09	17.3E09	17.3E09	16.7E09	17.3E09	16.7E09	17.3E09	20.4E10

Table C. 9 Monthly, directly deposited fecal coliform loads in each reach of Westover to Chippokes Pt. (NTU 91.1):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Loads
Human/Pet	28	36.6E10	33.0E10	36.6E10	35.4E10	36.6E10	35.4E10	36.6E10	36.6E10	35.4E10	36.6E10	35.4E10	36.6E10	43.0E11
Livestock	28	17.3E08	15.6E08	23.0E08	33.4E08	34.5E08	39.0E08	40.3E08	40.3E08	33.4E08	23.0E08	22.3E08	17.3E08	33.9E09
Wildlife	28	44.8E09	40.4E09	44.8E09	43.3E09	44.8E09	43.3E09	44.8E09	44.8E09	43.3E09	44.8E09	43.3E09	44.8E09	52.7E10
Human/Pet	29	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	29	72.9E07	65.9E07	97.2E07	14.1E08	14.6E08	16.5E08	17.0E08	17.0E08	14.1E08	97.2E07	94.1E07	72.9E07	14.3E09
Wildlife	29	12.3E09	11.1E09	12.3E09	11.9E09	12.3E09	11.9E09	12.3E09	12.3E09	11.9E09	12.3E09	11.9E09	12.3E09	14.4E10
Human/Pet	30	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	30	24.6E08	22.2E08	32.7E08	47.5E08	49.1E08	55.5E08	57.3E08	57.3E08	47.5E08	32.7E08	31.7E08	24.6E08	48.3E09
Wildlife	30	12.0E10	10.8E10	12.0E10	11.6E10	12.0E10	11.6E10	12.0E10	12.0E10	11.6E10	12.0E10	11.6E10	12.0E10	14.1E11
Human/Pet	31	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	31	40.9E07	37.0E07	54.6E07	79.2E07	81.9E07	92.4E07	95.5E07	95.5E07	79.2E07	54.6E07	52.8E07	40.9E07	80.4E08
Wildlife	31	38.2E09	34.5E09	38.2E09	37.0E09	38.2E09	37.0E09	38.2E09	38.2E09	37.0E09	38.2E09	37.0E09	38.2E09	45.0E10
Human/Pet	32	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	32	49.9E07	45.0E07	66.5E07	96.5E07	99.7E07	11.3E08	11.6E08	11.6E08	96.5E07	66.5E07	64.3E07	49.9E07	98.0E08
Wildlife	32	21.9E09	19.8E09	21.9E09	21.2E09	21.9E09	21.2E09	21.9E09	21.9E09	21.2E09	21.9E09	21.2E09	21.9E09	25.8E10
Human/Pet	33	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	33	89.4E06	80.7E06	11.9E07	17.3E07	17.9E07	20.2E07	20.8E07	20.8E07	17.3E07	11.9E07	11.5E07	89.4E06	17.6E08
Wildlife	33	68.5E08	61.8E08	68.5E08	66.2E08	68.5E08	66.2E08	68.5E08	68.5E08	66.2E08	68.5E08	66.2E08	68.5E08	80.6E09
Human/Pet	34	64.0E10	57.8E10	64.0E10	61.9E10	64.0E10	61.9E10	64.0E10	64.0E10	61.9E10	64.0E10	61.9E10	64.0E10	75.3E11
Livestock	34	17.3E08	15.6E08	23.0E08	33.4E08	34.5E08	39.0E08	40.3E08	40.3E08	33.4E08	23.0E08	22.3E08	17.3E08	33.9E09
Wildlife	34	68.2E09	61.6E09	68.2E09	66.0E09	68.2E09	66.0E09	68.2E09	68.2E09	66.0E09	68.2E09	66.0E09	68.2E09	80.3E10
Human/Pet	35	36.6E10	33.0E10	36.6E10	35.4E10	36.6E10	35.4E10	36.6E10	36.6E10	35.4E10	36.6E10	35.4E10	36.6E10	43.0E11
Livestock	35	15.5E08	14.0E08	20.6E08	30.0E08	31.0E08	34.9E08	36.1E08	36.1E08	30.0E08	20.6E08	20.0E08	15.5E08	30.4E09
Wildlife	35	69.1E09	62.4E09	69.1E09	66.9E09	69.1E09	66.9E09	69.1E09	69.1E09	66.9E09	69.1E09	66.9E09	69.1E09	81.4E10

Table C. 10 Existing annual (2012) loads from land-based sources of Westover to Chippokes Pt. (NTU 91.1):

Source	LMIR	Pasture	Commercial	LAX	Open Space	Crop	Wetland	Barren	Water	Forest
Beaver	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	59.3E09	00E00
Beef	00E00	13.5E13	00E00	55.1E11	00E00	00E00	00E00	00E00	71.2E10	00E00
Beef calves	00E00	59.0E12	00E00	22.6E11	00E00	00E00	00E00	00E00	31.1E10	00E00
cats	75.3E06	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Deer	16.3E10	41.9E12	10.2E08	13.6E10	52.0E10	29.8E12	22.3E12	21.6E11	00E00	17.8E13
dogs	84.0E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Duck	46.9E06	24.2E08	00E00	33.3E07	10.7E07	23.9E08	34.6E09	44.1E07	00E00	25.3E09
Goose	50.0E08	25.8E10	00E00	35.4E09	11.4E09	25.5E10	36.8E11	47.0E09	00E00	27.0E11
Hog	00E00	31.4E11	00E00	00E00	00E00	56.7E12	00E00	00E00	00E00	00E00
Horse	00E00	18.5E13	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Muskrat	16.2E10	83.3E11	00E00	11.5E11	36.8E10	82.4E11	11.9E13	15.2E11	00E00	87.2E12
People On Failing Septics	13.8E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
People on Straight Pipes	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	33.4E12	00E00
Raccoon	17.1E11	23.6E13	14.1E09	17.8E11	46.4E11	17.6E13	13.7E13	29.5E12	00E00	10.7E14
Sheep	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Turkey	24.1E06	63.8E08	67.1E03	32.0E06	12.1E07	47.5E08	10.3E09	71.7E07	00E00	81.4E09

Table C. 11 Existing annual loads from direct-deposition sources of Westover to Chippokes Pt. (NTU 91.1):

Source	Annual Total Loads (cfu/yr)
Beaver	59.3E09
Beef	71.2E10
Beef calves	31.1E10
Deer	69.4E10
Duck	55.5E08
Goose	38.9E10
Hog	00E00
Horse	00E00
Muskrat	23.1E12
People on Straight Pipes	33.4E12
Raccoon	42.2E11
Sheep	00E00
Turkey	26.3E07

Table C. 12 Current conditions of land applied fecal coliform load of Chippokes Pt. to Claremont (NTU 90.2):

Land-use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
LMIR	22.0E11	19.8E11	21.7E11	20.8E11	21.4E11	20.6E11	21.0E11	21.0E11	20.3E11	20.9E11	20.3E11	21.5E11	25.1E12
Barren	68.9E10	62.2E10	68.9E10	66.7E10	68.9E10	66.7E10	68.9E10	68.9E10	66.7E10	68.9E10	66.7E10	68.9E10	81.1E11
Forest	47.1E12	42.6E12	47.1E12	45.6E12	47.1E12	45.6E12	47.1E12	47.1E12	45.6E12	47.1E12	45.6E12	47.1E12	55.5E13
Pasture	25.1E12	22.7E12	25.0E12	23.9E12	24.7E12	23.8E12	24.6E12	24.6E12	23.9E12	25.0E12	24.2E12	25.1E12	29.2E13
LAX	43.7E10	39.5E10	59.1E10	76.2E10	78.7E10	91.1E10	94.2E10	94.2E10	76.2E10	59.1E10	57.2E10	43.7E10	81.3E11
Open Space	16.0E10	14.4E10	16.0E10	15.4E10	16.0E10	15.4E10	16.0E10	16.0E10	15.4E10	16.0E10	15.4E10	16.0E10	18.8E11
Crop	54.1E11	48.9E11	54.1E11	52.4E11	54.1E11	52.4E11	54.1E11	54.1E11	52.4E11	54.1E11	52.4E11	54.1E11	63.7E12
Wetland	58.1E11	52.4E11	58.1E11	56.2E11	58.1E11	56.2E11	58.1E11	58.1E11	56.2E11	58.1E11	56.2E11	58.1E11	68.4E12

Table C. 13 Monthly, directly deposited fecal coliform loads in each reach of Chippokes Pt. to Claremont (NTU 90.2):

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	1	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	1	10.7E08	96.8E07	14.3E08	20.8E08	21.4E08	24.2E08	25.0E08	25.0E08	20.8E08	14.3E08	13.8E08	10.7E08	21.1E09
Wildlife	1	17.9E10	16.2E10	17.9E10	17.4E10	17.9E10	17.4E10	17.9E10	17.9E10	17.4E10	17.9E10	17.4E10	17.9E10	21.1E11
Human/Pet	8	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	8	99.8E08	90.1E08	13.3E09	19.3E09	20.0E09	22.5E09	23.3E09	23.3E09	19.3E09	13.3E09	12.9E09	99.8E08	19.6E10
Wildlife	8	29.7E10	26.8E10	29.7E10	28.7E10	29.7E10	28.7E10	29.7E10	29.7E10	28.7E10	29.7E10	28.7E10	29.7E10	35.0E11
Human/Pet	9	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	9	89.4E07	80.7E07	11.9E08	17.3E08	17.9E08	20.2E08	20.8E08	20.8E08	17.3E08	11.9E08	11.5E08	89.4E07	17.6E09
Wildlife	9	21.3E09	19.2E09	21.3E09	20.6E09	21.3E09	20.6E09	21.3E09	21.3E09	20.6E09	21.3E09	20.6E09	21.3E09	25.0E10
Human/Pet	10	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	10	41.1E08	37.1E08	54.8E08	79.6E08	82.2E08	92.8E08	95.9E08	95.9E08	79.6E08	54.8E08	53.0E08	41.1E08	80.8E09
Wildlife	10	70.9E09	64.0E09	70.9E09	68.6E09	70.9E09	68.6E09	70.9E09	70.9E09	68.6E09	70.9E09	68.6E09	70.9E09	83.4E10
Human/Pet	11	18.3E10	16.5E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	18.3E10	17.7E10	18.3E10	17.7E10	18.3E10	21.5E11
Livestock	11	22.3E09	20.2E09	29.8E09	43.2E09	44.7E09	50.4E09	52.1E09	52.1E09	43.2E09	29.8E09	28.8E09	22.3E09	43.9E10
Wildlife	11	59.3E09	53.6E09	59.3E09	57.4E09	59.3E09	57.4E09	59.3E09	59.3E09	57.4E09	59.3E09	57.4E09	59.3E09	69.8E10
Human/Pet	12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Livestock	12	53.6E07	48.4E07	71.5E07	10.4E08	10.7E08	12.1E08	12.5E08	12.5E08	10.4E08	71.5E07	69.2E07	53.6E07	10.5E09
Wildlife	12	18.5E09	16.7E09	18.5E09	17.9E09	18.5E09	17.9E09	18.5E09	18.5E09	17.9E09	18.5E09	17.9E09	18.5E09	21.8E10
Human/Pet	13	27.4E10	24.8E10	27.4E10	26.5E10	27.4E10	26.5E10	27.4E10	27.4E10	26.5E10	27.4E10	26.5E10	27.4E10	32.3E11
Livestock	13	17.9E08	16.1E08	23.8E08	34.6E08	35.7E08	40.4E08	41.7E08	41.7E08	34.6E08	23.8E08	23.1E08	17.9E08	35.1E09
Wildlife	13	46.9E09	42.4E09	46.9E09	45.4E09	46.9E09	45.4E09	46.9E09	46.9E09	45.4E09	46.9E09	45.4E09	46.9E09	55.2E10

Table C. 14 Existing annual (2012) loads from land-based sources of Chippokes Pt. to Claremont (NTU 90.2):

Source	LMIR	Pasture	Commercial	LAX	Open Space	Crop	Wetland	Barren	Water	Forest
Beaver	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	21.0E09	00E00
Beef	00E00	23.2E12	00E00	11.0E11	00E00	00E00	00E00	00E00	12.2E10	00E00
Beef calves	00E00	12.9E13	00E00	60.1E11	00E00	00E00	00E00	00E00	67.8E10	00E00
cats	19.7E06	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Deer	23.9E09	11.2E12	00E00	52.0E09	16.8E10	10.6E12	52.1E11	50.6E10	00E00	71.7E12
dogs	21.9E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Duck	23.1E06	59.0E07	00E00	91.2E06	47.7E06	34.8E07	92.0E08	14.6E07	00E00	10.5E09
Goose	24.6E08	62.8E09	00E00	97.2E08	50.8E08	37.1E09	97.9E10	15.6E09	00E00	11.2E11
Hog	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Horse	00E00	61.9E12	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Muskrat	79.6E09	20.3E11	00E00	31.4E10	16.4E10	12.0E11	31.7E12	50.3E10	00E00	36.3E12
People on Failing Septics	27.8E11	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
People on Straight Pipes	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00	75.3E11	00E00
Raccoon	31.7E10	65.2E12	00E00	64.3E10	15.4E11	51.9E12	30.5E12	70.8E11	00E00	44.6E13
Sheep	00E00	30.8E10	00E00	00E00	00E00	00E00	00E00	00E00	00E00	00E00
Turkey	39.3E05	17.6E08	00E00	96.2E05	32.3E06	17.2E08	24.2E08	17.7E07	00E00	32.9E09

Table C. 15 Existing annual loads from direct-deposition sources of Chippokes Pt. to Claremont (NTU 90.2):

Source	Annual Total Loads (cfu/yr)
Beaver	21.0E09
Beef	12.2E10
Beef calves	67.8E10
Deer	25.1E10
Duck	15.0E08
Goose	10.5E10
Hog	00E00
Horse	00E00
Muskrat	62.6E11
People on Straight Pipes	75.3E11
Raccoon	15.3E11
Sheep	00E00
Turkey	98.6E06